STUDIES ON NEW ZEALAND CENOZOIC MOLLUSCA, INCLUDING THE EOCENE MOLLUSCA OF McCULLOUGH'S BRIDGE, WAIHAO RIVER, SOUTH CANTERBURY.

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Frontispiece: Type locality of the Tahuian Stage, right bank Waihao R. c. 100 m downstream from McCullough's Bridge. The most richly fossiliferous unit, the Tahu Member weathers to a somewhat darker colour than immediately underlying and overlying units, and is truncated by river gravels on the left end of the exposure.

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Introduction

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GENERAL INTRODUCTION

STATE OF KNOWLEDGE OF NEW ZEALAND CENOZOIC MOLLUSCAN FAUNA

New Zealand is generally considered to have an exceptionally complete record of marine Cenozoic rocks, represented by a wide range of lithofacies indicative of environments ranging from at least the sublittoral to the bathyal zones. As a consequence, it boasts a very rich fossil molluscan fauna, a fact that led Fleming (1966a: 1149) to state that "the New Zealand Tertiary offers a record of the history of a molluscan fauna of coastal and offshore habitats perhaps unequalled anywhere else in the world". This may be true, but this fauna is still very imperfectly known, despite the considerable attention it has received in the last 100 years. Fleming (1966a: 1150; 1966b: 13) recorded about 2,915 named species-group taxa from the Cenozoic, and if fossil taxa named since then are taken into account, together with Recent species that have subsequently been recorded as fossils, the figure is probably well in excess of 3,000. Nonetheless, this must constitute only a small fraction of the total molluscan fauna that has lived in the New Zealand region in the last 65 million years.

To date, some 1,800 living, shelled marine molluscs have been named from New Zealand waters and, judging from existing collections, particularly in the National Museum, another 2-300 await description. It is reasonable to assume that a similarly diverse fauna has existed throughout the Cenozoic. The diversity may well have been much higher at some times (e.g. during the Lower Miocene when the climate was substantially warmer), and considerably lower at other times (e.g. during

the late Eocene to early Oligocene when New Zealand was largely submerged and there were presumably fewer available ecological niches), but a figure of 2,000 for the "average" diversity is probably a reasonable guess. No studies have yet been made on the average longevity of molluscan species in New Zealand, nor has any attempt been made to calculate the time taken for a given percentage of the fauna to be replaced, but it may be noted that there are remarkably few species listed in Fleming (1966b) that have a recorded range of more than 2 stages and that a substantial number are known only from one stage. It is difficult to know how meaningful such an observation is, partly because the duration of New Zealand stages varies widely (the average is 2.4 million years), and partly because the stratigraphic ranges are very imperfectly known for most species, but we may infer that the New Zealand molluscan fauna has undergone a virtually complete turnover between 5 and 10 times in the last 65 million years, indicating a total fauna of 10-20,000 species-group taxa. (The time taken for a complete turnover is probably commensurate with the total duration of the Cenozoic, judging by the presence of the highly conservative, extant bivalve Hiatella australis (Lamarck) in an early Eocene fauna from North Canterbury). Of course, the total knowable fauna is much less, due partly to the incompleteness of the stratigraphic record, and partly to the poor preservation of some faunas, but it is unlikely to be less than 5,000 taxa, as there are at least 1,000 undescribed species and subspecies in the Geological Survey collections alone and an additional 1,000 could probably be obtained by assiduous collecting.

The above discussion, unsatisfactory as it may be, suggests that at the most, only 60% of the total recoverable fauna has been described. The reasons for this state of affairs can be summarised as follows:

1) Lack of workers compared with the situation in Europe and North America. New Zealand was not extensively settled by Europeans until the mid-19th century and the first fossil molluscs to be named were those described by the Austrian paleontologist Karl Zittel in 1864. It was not until 1873 that a New Zealand resident, Captain F.W. Hutton, described local Cenozoic molluscs. Since then the description of the Cenozoic molluscan fauna has proceeded in fits and starts, but even during the so-called "Golden Age of Molluscan Systematics" which lasted from 1923-42 (Fleming 1966a) there were only 4 major workers in the field, viz. H.J. Finlay, J. Marwick, A.W.B. Powell and C.R. Laws, and of these, only Marwick was a full-time paleontologist. Nonetheless, between them they added about 2,000 named species to the Cenozoic fauna, an achievement that if repeated would probably go a long way towards completing its description.

2) Influence of the "New Systematics". During the 1930's the whole philosophy of systematics was re-examined in the light of the biological species concept, which views species as populations and as dynamic systems that evolve both through internal changes and through the various processes of allopatric speciation. Fleming (1966a: 1173) suggested that this had the effect of slowing down the rate of description of new taxa, as it became obvious that insufficient attention had been paid to infraspecific variation in the past. As Fleming (op. cit.) notes, "if scores of specimens are to be measured, statistical analysis applied, and variation illustrated, one can no longer describe a dozen species in an afternoon". Quite apart from its effect on the description of new taxa, the "New Systematics" has made taxonomists look afresh at what has already been described, resulting in wholesale synonymisation of the numerous superfluous names that have been given to some species.

3) Decline in the use of Mollusca in Cenozoic biostratigraphy. Up until the late 1930's molluscs were the most useful tools available for biostratigraphic zonation of the New Zealand Cenozoic, and it was probably this geological aspect that gave the impetus to the taxonomic studies of such workers as F.W. Hutton, P. Marshall and J. Marwick. By the early 1940's it was apparent that molluscs would have to relinquish their pride of place to foraminifera, and it is probably significant that the rate of description of Cenozoic molluscs declined very sharply through the 1940's and 1950's (Fleming 1966a: 1173). Mollusca still have considerable stratigraphic importance, particularly in the Late Cenozoic, but the tendency today is to study them from a zoological viewpoint and for their intrinsic rather than pragmatic value.

4) Inefficient methods of describing new taxa. Publications that include descriptions of New Zealand Cenozoic molluscs can be divided into 4 rather broad categories which overlap to some degree, viz.:

a) Descriptions of faunas, usually from one locality, but occasionally from several localities within a geographically limited area. These vary greatly in scope and completeness, the most comprehensive to date being Finlay and Marwick's Paleontological Bulletin on the Wangaloan and related faunas from east Otago, published in 1937. Many of the papers in this category are largely confined to descriptions of new taxa, with little or no discussion of other members of the fauna, although faunal lists are usually included. In some cases the faunas (or more properly, faunules) are very small, and Marwick's Paleontological Bulletin on molluscs from the Gisborne district deals with a large number of small collections (more than 200), many of them with only 1 or 2 species each.

b) Reviews of particular groups of molluscs at the generic or a higher level. Most of the "classical" papers in this category date

from the "Golden Age" (1923-42) and tend to have a strong stratigraphic basis. They include reviews of such families as Naticidae, Veneridae, Volutidae and Struthiolariidae (Marwick), Pyramidellidae (Laws) and Turridae (Powell). Later papers tend to deal with genera rather than families (e.g. Bassina, Pecten, Sectipecten, Buccinulum, Xymene), an indication of the specialisation that becomes necessary as the quantity of available material increases. Of necessity, reviews also include discussion of previously named taxa and the number of new taxa named may be relatively small. Ponder's recent revision of Buccinulum reduces the number of species-group taxa recognised in this genus from 49 to 24, and describes only one new taxon, a Recent subspecies that is not known fossil. Similar overall reductions in the number of valid taxa may be expected when other groups (e.g. the Volutidae) are re-examined.

c) "General" papers in which taxa from a number of different localities and horizons are described, often without any rationale other than their supposed biological and/or geological interest.

d) Primarily geological papers in which molluscs are described, mainly because they are present in the area under discussion, and may have some stratigraphic significance.

A breakdown of all publications up to the end of 1973 that include descriptions of New Zealand Cenozoic molluscs is given below. This does not include papers that contain descriptions of Recent molluscs subsequently recorded as fossils, nor does it take into account the fact that some faunal descriptions (e.g. Laws' papers on Pakaurangi) and some group reviews (e.g. Laws' papers on pyramidellids) appeared in several parts.

Category	No. of publications	No. of new taxa described
a	40	1213
b	52	557
c	58	943
d	7	30

It is apparent from this analysis that the 4 different types of publications are not equally effective vehicles for describing the Cenozoic molluscan fauna, those falling into the first category (i.e. faunal descriptions) having a clear lead over the others in this respect. The comparative scarcity of such papers (less than 25% of all publications) is therefore all the more to be regretted.

The above discussion suggests that there are at least 4 factors which may explain why the New Zealand Cenozoic molluscan fauna is still rather poorly known. It is difficult to judge which is the most important as the various factors are not directly comparable, but in the writer's opinion it is the relative paucity of comprehensive faunal descriptions (partly related to the small number of workers in the field) that is largely to blame. New Zealand workers have not attempted to emulate the great European paleontologists such as Deshayes, Hoernes, Koenen, Bellardi, Sacco and Cossmann who devoted much of their time to compiling large faunal monographs, but have tended to describe the more obvious and seemingly more important taxa and ignore the apparently less interesting (usually small) forms. (C.R. Laws, who made a conscious effort to study minutiae, is a notable exception to this generalisation). This is shown by the large number of papers (58) that fall into the "general" category c) above. Reviews of individual genera or families are not numerous enough to fill in the gaps; in the bivalves alone, such important families as Nuculidae, Nuculanidae, Limopsidae, Pectinidae, Limidae, Ostreidae, Crassatellidae, Carditidae, Lucinidae, Mactridae, Tellinidae and Corbulidae have yet to be revised at the species level.

There are, of course, good reasons for this state of affairs, one being the comparative lack of man-power mentioned earlier. Another important factor is the increasing need for taxonomic specialisation;

if there are 200 species of molluscs in a fauna, it is unlikely that the average worker will be able to treat all of them to everybody's satisfaction, and may end up erecting a few synonyms in groups that he is not familiar with. Add to that the necessity for repeated visits to a locality before a reasonably representative collection can be made, and the time required for description, measuring and illustration, and it is little wonder that faunal monographs are not popular. Nonetheless, they are essential if the New Zealand Cenozoic fauna is to become adequately known in the near future.

SCOPE OF PRESENT WORK

The greater part of this thesis is devoted to a primarily taxonomic study of Eocene molluscs from McCullough's Bridge, Waihao River, one of the best-known fossil localities in the country, and certainly the one with the best-known Eocene molluscan fauna. It was collected first in 1886 (if not considerably earlier) and on numerous occasions since then, and is the type locality of at least 54 nominal species of molluscs (not including those described herein). The most recent published checklist (which appeared in 1926) includes 74 species; subsequent collecting by various workers, including the writer, has brought the total to 189 species, which is some indication of the value of making repeated visits to even well-known localities. In the present study all recorded species are discussed and all new species, type species of genus-group taxa (where these are present in the fauna) and poorly known species are fully described. Also included is a discussion of Upper Eocene molluscs from a recently discovered locality in the Waihao River near McCullough's Bridge.

The second part of the thesis is a "general" paper which includes nomenclatural and taxonomic discussion of Cenozoic molluscs from many

different parts of the country. The new species described therein are members of faunas that are very restricted or are unlikely to be treated as a whole in the near future, or belong to groups with a poor fossil record in New Zealand. They have been described primarily because of their taxonomic interest but some, at least, have paleoecological significance, particularly as indicators of warm conditions.

USE OF LOCAL STAGE NAMES

New Zealand Cenozoic stage and series names have been used throughout this thesis. The classification adopted, together with approximate international correlations, is set out below; this largely follows that adopted by Burns et al. (1973: Table 2) but with two exceptions, viz.:

a) The Wangaloan Stage is retained as a partial correlative of the Teurian, rather than rejected entirely as recommended by some micropaleontologists (e.g. Webb 1973). Webb's work suggests that the Wangaloan at its type locality and at Boulder Hill, Dunedin is either early-mid Teurian or even pre-Teurian. In view of this uncertainty, together with the great duration of the Teurian (probably equivalent to more than half of the Paleocene), the writer prefers to follow Fleming (1966b: 9) and retain the Wangaloan Stage until the New Zealand Paleocene is thoroughly revised.

b) Waitotaran is replaced by Waipipian and Mangapanian, following Beu (1969).

International		New Zealand	
Epoch		Series	Stage
Pleistocene		Hawera	
		Wanganui	Castlecliffian
			Nukumaruan
			Mangapanian
Pliocene			Waipipian
			Opoitian
	Upper	Taranaki	Kapitean
			Tongaporutuan
		Southland	Waiauan
Miocene	Middle		Lillburnian
			Clifdenian
		Pareora	Altonian
	Lower		Otaian
		Landon	Waitakian
Oligocene			Duntroonian
			Whaingaroan
	Upper	Arnold	Runangan
			Kaiatan
Eocene			Bortonian
	Middle	Dannevirke	Porangan
			Heretaungan
			Mangaorapan
	Lower		Waipawan
Paleocene			Teurian/ Wangaloan

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Burns, R.E. et al.: 1973. Initial Reports of the Deep Sea Drilling Project XXI. 2. Explanatory Notes: 5-16, 6 figs., 2 tables.

Fleming, C.A.: 1966a. The Description of the New Zealand Cenozoic Mollusca: A Historical Survey. New Zealand Journal of Geology and Geophysics 8(6): 1149-74, 16 figs.

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Webb, P.N.: 1973. A Re-examination of the Wangaloan Problem. New Zealand Journal of Geology and Geophysics 16(1): 158-69, 2 figs.

PART 1

EOCENE MOLLUSCA FROM THE VICINITY OF McCULLOUGH'S BRIDGE, WAIHAO RIVER, SOUTH CANTERBURY

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ABSTRACT

The molluscs discussed in this account are from two exposures in the Waihao River: a) the "classical" McCullough's Bridge locality (including the stratotype of the Tahuian Stage) which has yielded 189 species, 167 of them from the 2 m. thick Tahu Member of early Kaiatan age, the others from beds of late Bortonian to Kaiatan age; b) a recently discovered outcrop of tuffaceous sediments /Kapua Tuffs, also Kaiatan but younger than the beds at a)/ from which 46 species are recorded. 26 species are common to the Tahu Member and Kapua Tuffs. Molluscs indicate that the Tahu Member (and probably Kapua Tuffs) was deposited in subtropical waters of normal salinity at depths of at least 150-200 m. Neither fauna shows much similarity to other Arnold Series faunas, largely because of ecological factors.

In the systematic section, 206 species-group taxa are recorded and discussed. One new subfamily (of Nuculidae), 20 new genus-group taxa and 78 new species-group taxa are proposed and a further 25 new species are recorded but not named. A new supraspecific classification of the Nuculidae, based primarily on shell structure, is presented and the described New Zealand Cenozoic and Recent species are assigned to the relevant genus-group taxa. Reviews are also given of New Zealand internally costate pectens, the genus Falsicolus Finlay, 1930 (Fasciolariidae) and the New Zealand turrids formerly referred to Marshallena Finlay, 1927 and Marshallaria Finlay & Marwick, 1937. The following synonymies are proposed: Magnatica powelli Laws, 1932 with M. planispira (Suter, 1917), Tubena Marwick, 1943 with Gegania Jeffreys, 1884, Zexilia tenuilirata and Z. submarginata Laws, 1935 with Exilia (Zexilia) waihaoensis Suter, 1917,

Eoturris neglecta with *E. complicata* (Suter, 1917) and *Cordieria haasti* and *C. verrucosa* Finlay, 1930 with *C. rudis* (Hutton, 1885).

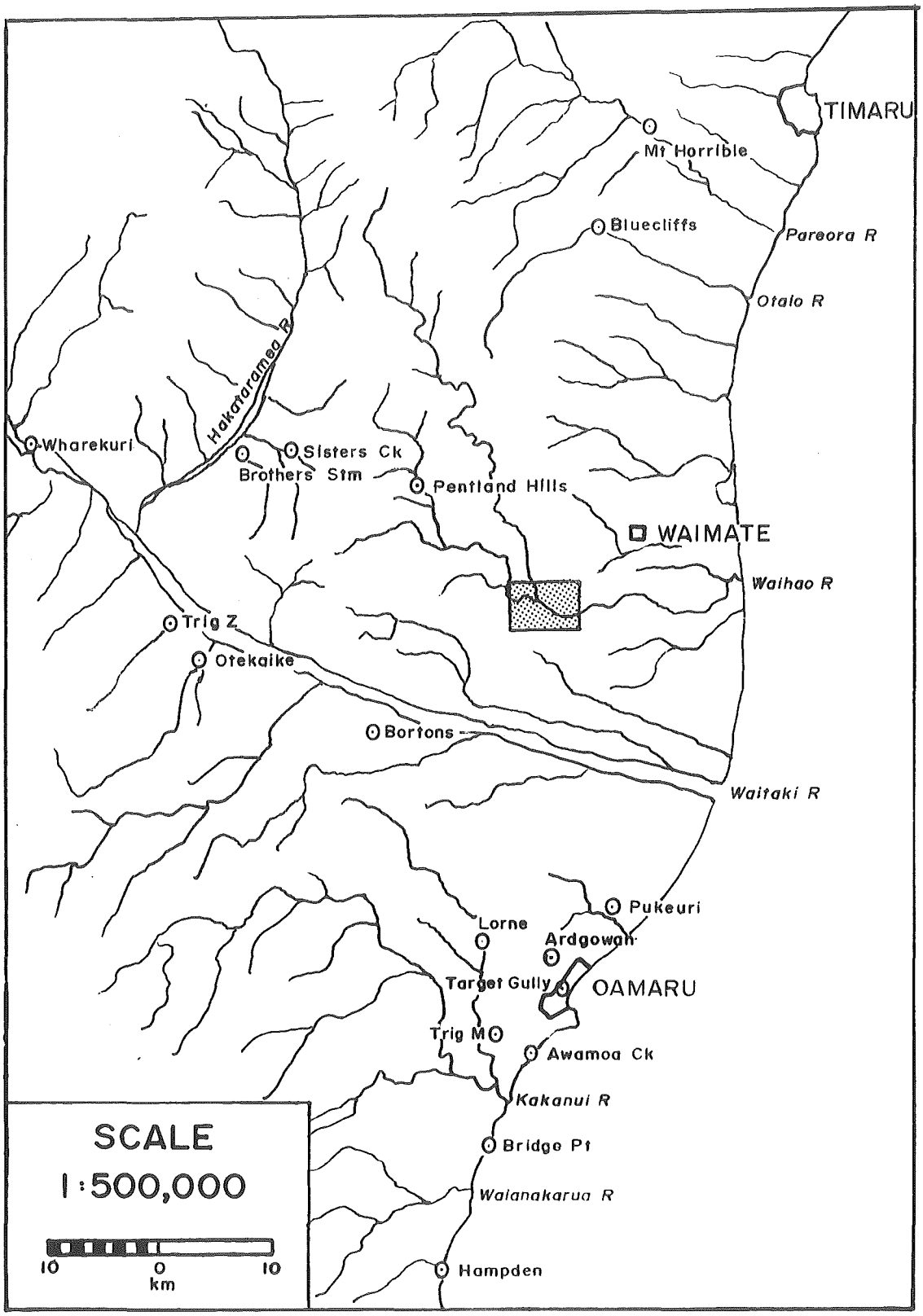
CHAPTER I

INTRODUCTION

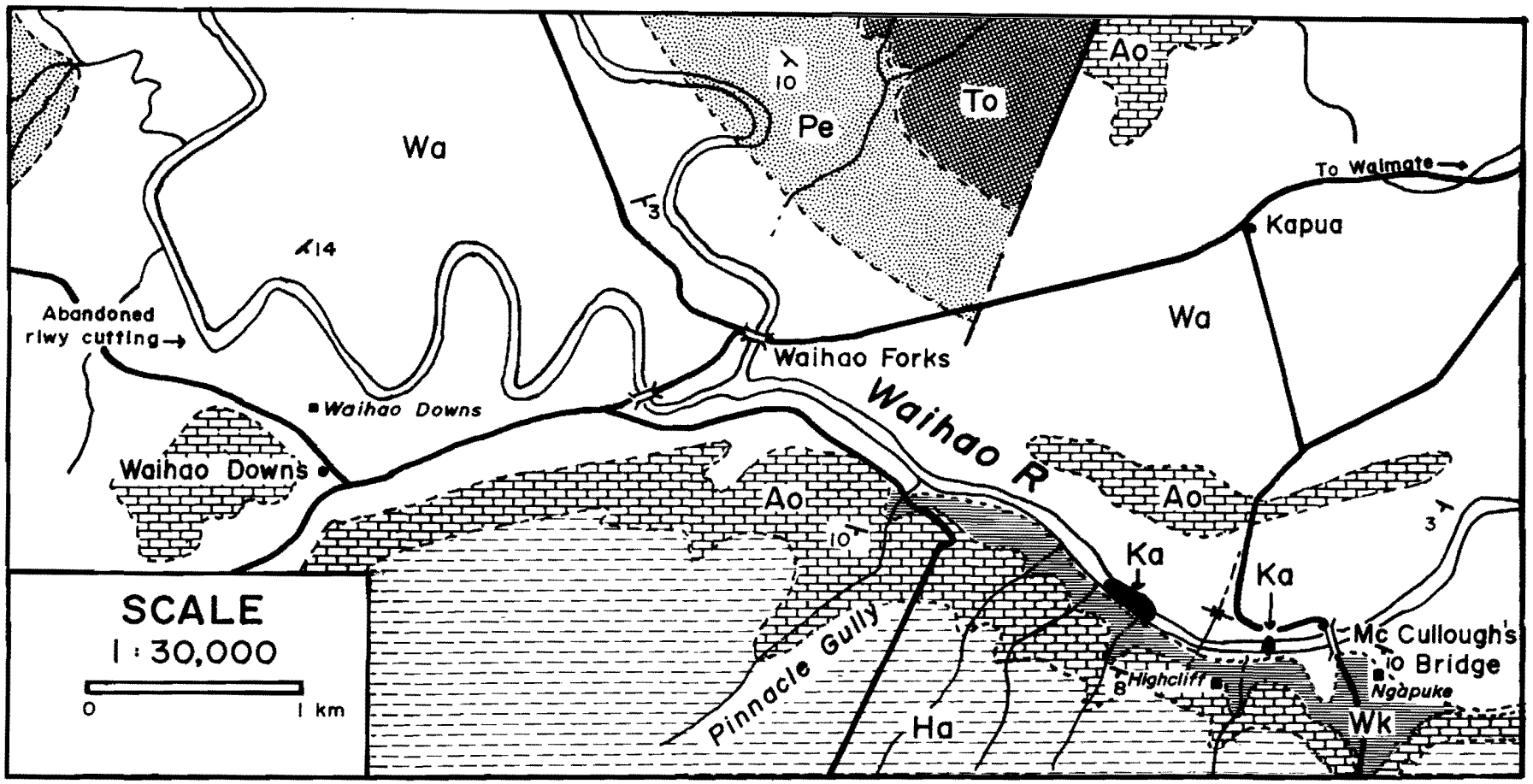
The low bluff on the right bank of the Waihao River, a short distance downstream from McCullough's Bridge, is the best-known Eocene macrofossil locality in New Zealand, and because of its easy access and the interesting nature of its fauna, it has been collected on numerous occasions by both professional palaeontologists and amateur fossil collectors. To date, 53 species of molluscs have been described from this locality, 9 of them the type species of genus-group taxa. In the present study the recorded fauna is increased to 189 species, 167 of them from one thin bed, the Tahu Member (see below), making it the largest Eocene molluscan fauna so far recorded from New Zealand. When it is realised that the upper part of the section is the type locality for the Tahuian stage (which was originally based on molluscs) it is surprising that the molluscan fauna has awaited monographic treatment for so long. However, as pointed out in the introduction to this dissertation, faunal monographs are the exception rather than the rule in New Zealand palaeontology.

1. LOCATION AND ACCESS

McCullough's Bridge, on the Waikakahi Valley Road, crosses the Waihao River about 11 km from the town of Waimate, South Canterbury, and about 3 km downstream from Waihao Forks (Text figs. 1, 2). Gently dipping glauconitic sands, calcareous siltstones and tuffs comprising the Waihao Greensands are exposed at intervals both upstream and downstream from the bridge. The molluscs discussed and



Text fig. 1. Map of part of North Otago and South Canterbury showing location of area covered in text fig. 2 and of the more important Cenozoic fossil localities mentioned in the text.



Text fig. 2. Geological map of lower Waihao Valley, taken largely from Riddolls (1966a). The following symbols are used for lithostratigraphic units - To, Torlesse Group; Pe, Pentland Hills Formation; Wa, Waihao Greensands; Ka, Kapua Tuffs; Wk, Waikakahi Formation; Ao, Arno Limestone; Ha, Mt Harris Formation.

described in this dissertation are from two localities:

(1) Glauconitic sands and siltstones exposed in a 7 m high terrace face on the right bank 100-200 m downstream from the bridge. /Grid reference NZMS1 S127/550024 (2nd ed.)/. This locality, shown in the frontispiece, is the "classical" McCullough's Bridge fossil locality, and was first collected in 1886 by Alexander McKay, if not considerably earlier by Julius van Haast (see Notes on Early Collections from Waihao Greensands, below).

Access to the McCullough's Bridge locality is simple and except during periods of flooding it is possible to drive down to beneath the bridge itself and then walk along the willow-covered bank to the outcrop.

Up until about 1967 the most fossiliferous unit, the Tahu Member, was exposed continuously for the whole length of the outcrop (about 100 m) but during a severe drought in 1966-7 the broom bushes that had stabilised the overlying Highcliff Siltstone died off, allowing large slips to obscure most of the more accessible part of the member. It is difficult to collect the remainder of the outcrop without using a ladder.

(2) Dark grey calcareous tuffs (Kapua Tuff Bed) forming a broad shelf some 200 m in length in the bed of the Waihao River, at and downstream from the site of a former ford, 1 km upstream from McCullough's Bridge. (Grid reference S127/535027).

Access is along a now largely disused public "road" on the left (north) bank of the river, leaving the Waikakahi Valley road at the sharp bend 0.3 km upstream from the bridge.

2. PREVIOUS INVESTIGATIONS

Early geological and paleontological studies of the Waihao district (including McCullough's Bridge) have been summarised in some detail by Allan (1926c). Several of the earlier papers, published between 1882 and 1888, concern a somewhat arid discussion between Alexander McKay and Captain F.W. Hutton on the relationship of the Waihao Greensands to the Waihao Limestone and Mount Harris Beds. Apart from the fact that this sometimes acrimonious debate was triggered by Hutton's study of molluscs from the Waihao Greensands, it is of little relevance to the present work and will not be discussed in any detail.

The first collections of molluscs from the Waihao Greensands were made by Julius von Haast in 1867-8 (McKay, 1887: 435) and in 1875 were sent, along with collections from three other South Canterbury localities, to Hutton for study. Hutton (1877) concluded that all four collections were from the "Pareora formation" (so starting the debate alluded to above), described two species (Lunatia suturalis and Leda semiteres) and recorded a third (Pecten hochstetteri Zittel) from "the greensands at Waiho" (sic). /Another species, Cladopoda directa, described by Hutton in one line without any locality details, is apparently also from the Waihao collection (Hutton 1888: 265)/. Haast (1879: 310) did not accept Hutton's view of the age of the Waihao Greensands and referred them to the Oamaru Formation, a term interpreted in various ways by early geologists (see Gage in Fleming 1959b: 268-9) but always as an older unit than Pareora Formation. Haast's list of fossils from the Oamaru Formation includes 17 molluscs from "Waihao", presumably those identified by Hutton in 1875.

In 1885 Hutton described two more molluscs from Waihao, viz.

Mitra inconspicua and Clathurella rudis, but another 32 years were to elapse before any further systematic work on the rich Waihao Greensands molluscan fauna was published. In Paleontological Bulletin 5, Suter (1917) described or recorded 37 species of molluscs (including some synonyms) from localities in the Waihao Greensands. Of these, 7 species were definitely from McCullough's Bridge (6 of them from GS 642, collected by A. McKay in 1886), 7 were from the disputed locality GS 630 (see Notes on Collections), 9 from GS 479, "marly Greensands, Waihao R", a collection that includes 4 species that may be from McCullough's Bridge (see Notes on Collections) and the remainder from either GS 480, "Island Sandstone, Waihao R.", or from Waihao Downs, localities of Bortonian (or even older) age. In several senses, Suter's bulletin marked the end of an era in molluscan paleontology in New Zealand. Both Hutton and Suter had been content to describe material collected by other workers; as a result their knowledge of the stratigraphic background of fossil collections was hazy or non-existent and much of what they studied was imprecisely localised. Although Suter's taxonomic work was of a higher order than Hutton's and his descriptions far more adequate, he frequently made serious misidentifications, even to the extent of failing to recognise his own taxa. Later workers were generally more conscious of the need for careful localisation of collections, had a better grasp of the associated stratigraphic problems and in most cases personally collected the material they studied.

In 1915 P. Marshall had included a list of 13 species of molluscs collected by G.H. Uttley from greensands at "McCulloch's Bridge" (sic) in a paper describing Cenozoic fossil localities in North Otago and South Canterbury. The same list was later included by Suter (1921: 67) in his "Lists of New Zealand Tertiary Mollusca"

along with similar compilations for GS 642 (given as 462 in error) (p. 63), GS 479 (p. 64-5), GS 630 (p. 79) and for a collection from McCullough's Bridge made by J.A. Thomson in 1917 (p. 66). Marshall (1923: 118-9) later presented an expanded checklist of 71 species of molluscs, based mostly on collections made by himself and R. Murdoch in 1921. In the following paper Marshall and Murdoch (1923) described 5 species of gastropods from McCullough's Bridge, one of them inadvertently attributed to "Pukeuri" (Maxwell 1966: 455).

In the early 1920's, probably in 1923-4, R.S. Allan studied the geology and paleontology of the Lower Waihao Basin, paying careful attention to the molluscan faunas of the Waihao Greensands. The results of his work were summarised briefly in Allan (1926b) and in more detail in Allan (1926a, 1926c). In the first paper, "Fossil Mollusca from the Waihao Greensands", 10 species were described from McCullough's Bridge and 6 from Waihao Downs and the "Island Sandstone".

Allan (1926b: 324, 1926c: 234) subdivided the Waihao Greensands into 3 lithostratigraphic units, a basal unit of cemented sandstone and conglomerate (the "Island Sandstone" of McKay), the "Lower Greensands" including the richly fossiliferous beds exposed in the South Branch of the Waihao R. near Waihao Downs) and the "Upper Greensands" for the beds above the "phosphatic sand" at McCullough's Bridge. He proposed the Waimatеian stage for the time represented by these beds, and on the basis of his careful work on the associated molluscan faunas subdivided it into two substages, a lower one that included the first two lithological units which he correlated with Park's Bortonian (originally proposed as a stage) and an upper one for the rest of the Waihao Greensands for which he proposed the name Tahuian. /Marwick (1927: 576) later elevated the Tahuian to full stage rank and the Waimatеian dropped from use/. Allan's checklist of McCullough's

Bridge molluscs (1926c: 291) includes 74 names (9 of them nomina nuda) and has remained the most complete and reliable compilation up to the present study.

Allan's work undoubtedly stimulated further studies on McCullough's Bridge molluscs, even though he himself later specialised almost exclusively in the study of brachiopods. His collection of naticids from the Waihao had already been studied by H.J. Finlay (1924) and later included in Marwick's revision of the New Zealand Naticidae (Marwick 1924a). When Allan left to study in Great Britain in 1926, his collections were donated to Finlay and probably formed the source of some of the types of species described by him in a later paper (Finlay 1930a) and by Powell (1942). Marwick (1926a, 1927, 1942) and Laws (1935a, b, 1937, 1941a) also included descriptions of McCullough's Bridge molluscs in papers published in this period. None of these workers, however, attempted to treat the molluscan fauna as a whole.

Allan (1933: 93-4) briefly outlined the sequence at McCullough's Bridge, presented a more rigorous definition of the Tahuian stage, and included a list of the "characteristic" molluscs. In their first paper on stratigraphic divisions of the late Cretaceous and Cenozoic in New Zealand, Finlay and Marwick (1940: 109-110) retained the Tahuian stage, listed 2 genera and 13 species of molluscs that they considered restricted to the unit, as well as several taxa that they thought made their first or last appearance at this time. A major difference between their paper and Allan's is the inclusion of evidence from foraminifera, particularly for the correlation of the Tahuian with beds beyond the type area. In their second paper, Finlay and Marwick (1947: 229) listed the Tahuian as equivalent to the Kaiatan stage. Hornibrook (in Fleming 1959b: 371-2) repeated

Allan's list of characteristic Tahuian molluscs, included a list of the foraminifera from the "Tahuian greensand" and mildly criticized Finlay and Marwick's action in removing the Tahuian stage, noting that "retention of the Tahuian Stage, its limits precisely defined by Allan, with good macro- and microfaunas and with its type locality not far from the Oamaru district, might well have been a better course than to base the New Zealand Upper Eocene stages on the West Coast sequence". At that time it was assumed, on the rather limited microfaunal evidence available, that the Bortonian-Kaiatan boundary in the McCullough's Bridge section coincided with the lithostratigraphic boundary between the upper and lower Waihao Greensands, i.e. at the so-called "phosphatic" band.

Srinivasan (1966: 509), through close sampling of the McCullough's Bridge section, showed that on the basis of the foraminifera, the Bortonian-Kaiatan boundary as understood by micropaleontologists lies some distance above the "phosphatic" sand. He suggested that most of the molluscs listed by Allan as being from the type Tahuian were in fact from the lower few feet of the upper greensands and therefore of Bortonian age. This was refuted by Maxwell (1967) who pointed out that the majority of molluscs collected from McCullough's Bridge are definitely from a narrow bed above Srinivasan's Bortonian-Kaiatan boundary.

From 1942 to 1966 no molluscs were described from McCullough's Bridge. This neglect seems to have been part of a general decline in molluscan systematics in New Zealand, partly due to the decreasing use made of molluscs for Cenozoic stratigraphic correlation (see Fleming 1965). In 1966 the writer described 7 species from McCullough's Bridge in a paper on Upper Eocene molluscs (Maxwell 1966) and two years later described the cymatiid Distorsio (Personella)

beui from the same locality (Maxwell 1968b). In a recent paper on Cenozoic muricids two species are described from McCullough's Bridge (Maxwell 1971).

3. SCOPE OF PRESENT STUDY

In this study, an attempt has been made to discuss all molluscan taxa so far recorded from McCullough's Bridge, paying particular attention to those from the most fossiliferous unit, the Tahu Member (described below). Complete descriptions are given for new taxa, for type species of genus-group taxa and for a number of species where the original descriptions are inadequate. Brief diagnoses are given for the remaining species. Molluscs from the Kapua Tuffs are also discussed and described for comparison with those from McCullough's Bridge.

The composition of the molluscan faunas from the Tahu Member and Kapua Tuffs is discussed in detail in order to ascertain how they relate to other New Zealand Cenozoic faunas, particularly those from the Arnold Series. The molluscan faunas are also used to draw conclusions about depth of deposition, salinity and palaeotemperatures.

CHAPTER II

STRATIGRAPHY AND AGE

Despite the importance of the McCullough's Bridge section to New Zealand Cenozoic biostratigraphy, the only published column is the simplified one given by Srinivasan (1966: 508) which covers less than 10 metres of section. Allan (1926c: 290) gives a reasonably detailed description of the section exposed on the right bank of the Waihao downstream from the bridge, but makes no mention of the stratigraphically higher beds upstream. The following descriptions are based on field-notes made by the writer in 1968-71. A summary of the stratigraphic succession in the Waihao Valley is given in Table 1.

1. NOTE ON APPLICABILITY OF NAME "WAIHAO GREENSANDS"

Riddolls (1966a) has pointed out that the name "Waihao" has been used for three distinct lithostratigraphic units, viz. Waihao Formation (Haast 1879), Waihao Greensands (McKay 1882) and Waihao Limestone (Hector 1882). The first name was applied to partly metamorphosed rocks of late Paleozoic-Mesozoic age now included in the Haast Group (Suggate 1961) and does not appear to have gained wide acceptance by subsequent workers. Adkin (1954: 104) lists 8 references to "Waihao Formation", the most recent being that of Park (1904: 450) who merely placed it in synonymy of Kakanui "Series". Apart from an entry in the Stratigraphic Lexicon (Grindley in Fleming 1959: 429) and inclusion in a list of stratigraphic names that have been used for the schistose facies of the Torlesse Group (Suggate 1961: 398) the term "Waihao Formation" has been almost entirely ignored for 70 years. "Waihao Greensands" and "Waihao

Age	Formation	Lithology
Waitakian-Altonian	Mount Harris Formation	Moderately to slightly calcareous siltstones and sands, locally with common molluscs, glauconitic at base.
Duntroonian-Waitakian	Arno Limestone	Hard sandy limestone, typically concretionary and cross-bedded, with basal phosphatic greensand containing common brachiopods and echinoids
Whaingaroan	Waikakahi Formation	Moderately glauconitic, bioturbated limestone
Bortonian-Runangan	Waihao Greensands	Micaceous, glauconitic sands and siltstone, locally with common macrofossils. Concretionary sandstone and conglomerate at base, thin tuff bed (Kapua Tuffs) near top
Teurian/Wangaloan-late Dannevirke Series?	Pentland Formation	Quartzose conglomerates and sands, locally highly carbonaceous with some minor coal beds, resting unconformably on greywackes, etc. of Torlesse Supergroup

Table 1. Generalised stratigraphic succession, Paleocene-Lower Miocene, Lower Waihao Valley. Data partly from Allan (1926c) and Riddolls (1966a). Not to scale.

Limestone", on the other hand, have been used at sporadic intervals ever since they were first proposed; Adkin (1954: 104-5) gives 7 references between 1887 and 1926 for the former name and 10 references (between 1882 and 1929) for the latter. Additional references to "Waihao Greensands" (besides those given by Adkin) are in Allan (1926a, c), Finlay (1930a), Marwick (1927), Maxwell (1966, 1968, 1971) and Squires (1958). It is apparent that the name has been widely accepted by paleontologists at least, and that unlike the prior "Waihao Formation" it has become firmly entrenched in geological literature. Gage (in Fleming 1959: 430) notes that "Waihao Greensand is likely to be retained as a lithogenetic unit in the Waihao Valley and adjacent areas of S. Canterbury".

"Waihao Limestone" has been used less frequently by paleontologists than has "Waihao Greensand", probably because fewer fossils have been described from that unit; however, it is referred to by Hornibrook (1961) and, in a more informal way, by Finlay (in Marples 1952: 62).

A strict application of the principle of priority to the names Waihao Formation, Waihao Greensands and Waihao Limestone, as suggested by Riddolls, would of course lead to rejection of the two latter names. Riddolls replaces them with McCullough's Formation and Arno Limestone. The writer, however, feels that in this case priority is less important than accepted usage and that both Waihao Greensands and Waihao Limestone score heavily over Waihao Formation on this count. Accordingly, the name Waihao Greensands is used throughout this work in preference to Riddolls' substitute name; Arno Limestone is, however, used instead of Waihao Limestone although the writer feels that in practice there is little possibility of confusing the greensands with the limestone in the Waihao district.

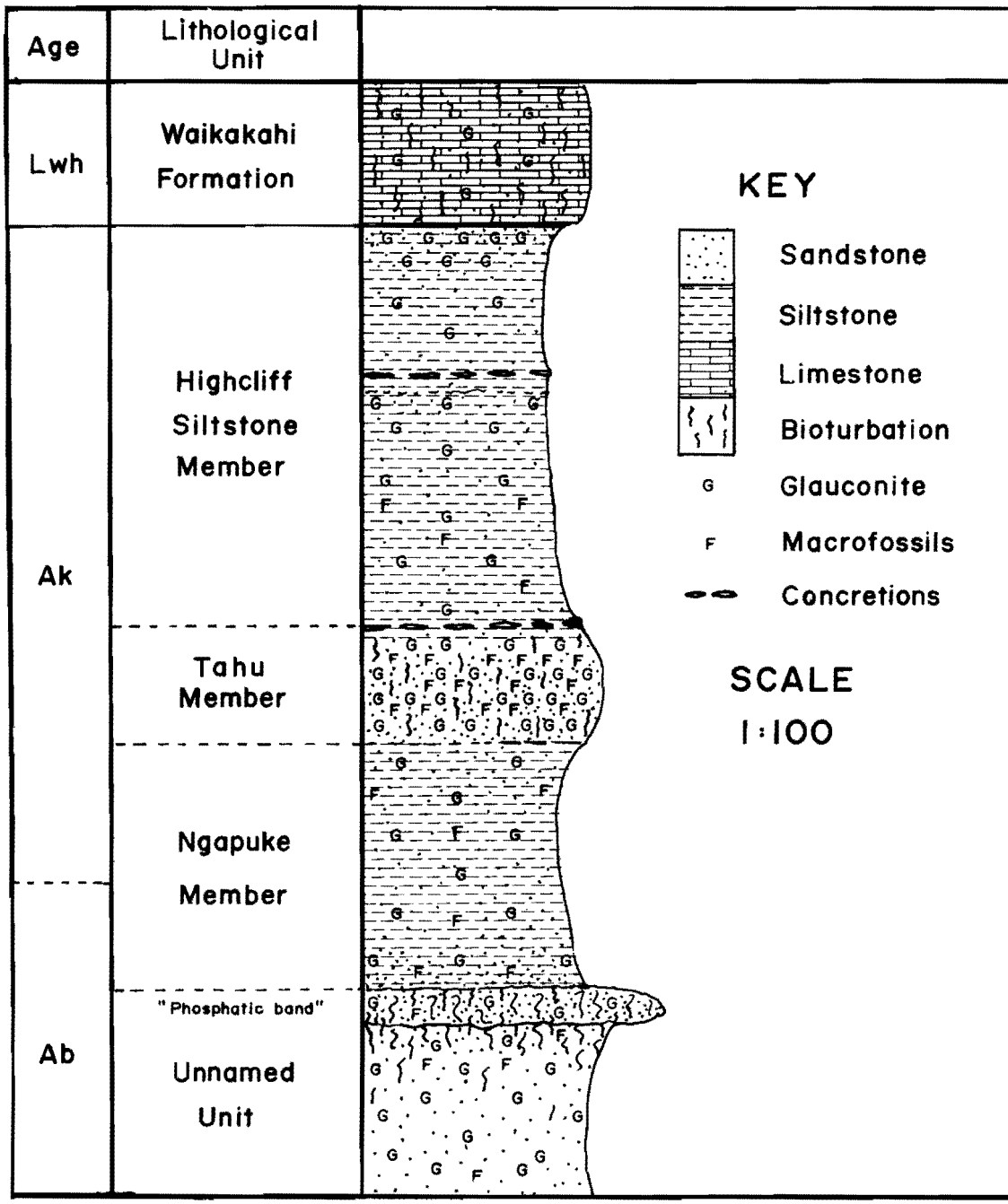
2. McCULLOUGH'S BRIDGE SECTION (Text fig. 3)

(In the following description, the beds are described in ascending order).

1. The lowest beds examined are soft blue-grey (dark when wet) micaceous sands with 15-20% by volume of glauconite. Macrofossils (poorly preserved corals) are rare in the lower part, more common (though still scattered) in the top metre or so. In the uppermost half metre numerous burrows up to 8 cm in length are picked out by the higher glauconite content of the infilling matrix. The only molluscs collected by the writer from this unit are the bivalves Duplipecten parki (Marwick) and Pycnodonte mackayi (Suter) though other, badly crushed and poorly preserved bivalves and gastropods were noted in the field. The holotype of Nemocardium carteri n.sp. is also from this bed. The thickness exposed is about 3 m.

Allan (1926c: 290) tentatively correlated this bed with the "Lower greensands" well exposed in both branches of the Waihao River upstream from Waihao Forks. The molluscan evidence is too scanty to confirm such a correlation but Duplipecten parki is certainly quite common in the upper part of the Waihao Greensands exposed in the South Branch near "Waihao Downs" homestead. There it is associated with a rich Bortonian molluscan fauna including Falsicolus (Liracolus) bensoni (Allan), Fascioplex neozelanicus (Suter) and Speightia spinosa (Suter).

Microfaunal evidence for a Bortonian age for the lowest beds exposed at McCullough's Bridge is more definite; Srinivasan (1966: 506) obtained a small foraminiferal fauna from a sample taken 6 ft (1.8 m) below the "phosphatised band". This includes Rectuvigerina prisca (Finlay), a benthonic species which is restricted to the Bortonian.



Text fig. 3. Stratigraphic column, section exposed in right bank Waihao R., 50-150 m downstream from McCullough's Bridge. The units are described in the text. Stage symbols: Ab, Bortonian; Ak, Kaiatan; Lwh, Whaingaroan.

2. Overlying the micaceous sands is a prominent cemented sandstone band up to 0.6 m thick, quite resistant to weathering and, until a few years ago, forming a broad, gently dipping shelf at the eastern end of the section that is now largely overgrown. Upper and lower limits of the band are not sharply marked, but prominent, cemented horizontal burrows are common in the top few cm. The band is typically rusty-brown with occasional dingy green patches on weathered surfaces. The only macrofossils seen in the cemented band were a few poor corals and bivalves that defied collection.

The cemented band was first mentioned by Wild and Speight (1919: 185) and thereafter by all subsequent workers discussing the stratigraphy of the McCullough's Bridge section. /Although usually referred to as the "phosphatic" or "phosphatised" band, the phosphate content is in fact quite low (A.R. Edwards, oral comm.) and the term "cemented band" is preferred/. Allan (1926c: 274) considered the presumed phosphatisation and the marked difference between molluscan faunas from the greensands above and below the cemented band good evidence for a long hiatus in deposition. The boundary between the Tahuian and Bortonian substages was accordingly taken to coincide with the lithological boundary between the upper greensands and the top of the cemented band (see previous section).

Srinivasan (1966: 507) obtained Bortonian Foraminiferida, including Gaudryina proreussi Finlay, from samples taken at the base and near the top of the cemented band.

3. The cemented band is overlain by a rather similar but non-cemented, dingy-green to rusty brown glauconitic sandstone about 0.5 m thick. Macrofossils are moderately common though normally rather crushed and of chalky texture, and include corals (Flabellum sp.) and molluscs /Saccella semiteres (Hutton), Pseudoportlandia sp.,

Notocorbula allani n.sp. and Magnatica (Spelaenacca) parilis Finlay]. The types of Serripecten marwicki n.sp. and Moerella aotea n.sp. are from immediately above the cemented band; the holotype of Serripecten tahuianus Laws is probably from a similar horizon.

This sandstone passes up gradually into a soft light grey (dry) silty glauconitic sandstone with numerous ferruginous and jarosite-weathering nodules and scattered macrofossils. Glauconite is irregularly distributed, tending to be abundant in small patches, deficient in others, giving the sandstone a blotchy appearance that is presumably caused by bioturbation. Molluscs are not well-preserved but Cucullaea cf. waihaoensis Allan and an extremely fragile astraeine turbinid (? Bolma sp.) occur in the upper 2 m or so.

The total thickness of this unit, hereafter referred to as the Ngapuke Member (after "Ngapuke" homestead, c. 200 m S. of McCullough's Bridge) is 4.5 m. Prior to the work of Srinivasan (1966) it was thought to be Kaiatan throughout; however, it is now known that the lower part of the unit is Bortonian. Srinivasan (1966: 507-8) obtained a small microfauna of probable Bortonian age from 6 ft (1.8 m) and a Kaiatan microfauna from 11 ft (3.3 m) above the cemented band; the Bortonian-Kaiatan boundary was therefore rather arbitrarily taken as about 8 ft (2.4 m) above the cemented band. Miss A. Cameron's work suggests that the boundary [taken as marked by the initial appearance of Gaudryina reussi (Stache)] should be placed a little lower - at 2 m (pers. comm.).

Srinivasan also suggested that most of the molluscs listed by Allan (1926c: 291) from the type Tahuian were from the lower (i.e. Bortonian) part of the Ngapuke Member and that this accounted for the moderately high percentage (27%) of molluscs alleged to be common to McCullough's Bridge and Hampden (also Bortonian). This was refuted

by the writer (1967) who pointed out that nearly all the molluscs recorded from McCullough's Bridge are from a unit (Tahu Member - see below), stratigraphically well above Srinivasan's Bortonian-Kaiatan boundary, though within his Gaudryina reussi Zone marked by the concurrence of G. reussi with the planktonic foraminifer Pseudoglobo-quadrina primitiva (Finlay).

4. The Ngapuke Member passes up fairly quickly into a soft, medium greenish-grey (dry) glauconitic silty sandstone with a distinctive light chocolate brown weathering crust, somewhat more resistant to weathering than the underlying unit and so producing a slight overhang. The glauconite content is high (c. 30%) but the mineral is not uniformly distributed, showing local concentration in what are assumed to be burrow structures. The ferruginous nodules so common in the upper part of the Ngapuke Member are absent. In the top 0.5 m the sandstone becomes siltier and less glauconitic and is capped by a persistent band of irregular tabular concretions up to 1.5 cm thick. Macrofossils, chiefly molluscs but including brachiopods, corals, crab chelae etc., are common, diverse and generally well-preserved, although some specimens are slightly crushed. The fossils tend to be uniformly scattered throughout the unit but locally form poorly defined "pockets" of two or three specimens. There are no definite shell-rich lenses, or stringers. This unit, which is here named the Tahu Member, is 2 m thick.

Nearly all the molluscs recorded from McCullough's Bridge, including the 74 species listed by Allan (1926c: 291) are from the Tahu Member; very few of them are also recorded from the underlying or overlying members (see Checklist). Allan (1926c: 290) noted that "any one species is not abundant, but the remarkable feature is the great variety of forms, chiefly gastropods, which one can obtain from

the small section exposed". This statement needs some modification as a number of species are generally well-represented in collections and can be described as "dominant" but it is certainly true that the majority of the 167 molluscs included in the checklist are represented by only a few specimens each and in some cases by only one specimen [e.g., Distorsio (Personella) beui Maxwell], despite numerous visits to the locality between 1959 and 1972. New forms will undoubtedly continue to turn up in the Tahu Member but probably at an ever-decreasing rate. The numerically most abundant molluscs from the Tahu Member are listed below. A few (Austrotindaria, Notolimopsis and Pareora) are small forms overlooked by previous collectors, but common in matrix washings.

Saccella semiteres (Hutton)

Austrotindaria delli n.sp.

Notolimopsis hampdenensis (Marshall)

Dentalium (Fissidentalium) waihaoense n.sp.

Dentalium (s.l.) delli n.sp.

Fustiaria (Gadilina) maoria n.sp.

Spirocolpus waihaoensis (Marwick)

Zeacolpus lornensis (Marwick)

Pareora sublaevis Maxwell

Friginatica (Sulconacca) suturalis (Hutton)

Tahunacca haasti (Marwick)

Lathyrulus fraudator n.sp.

Waimatea inconspicua (Hutton)

Conomitra plicatella (Marshall and Murdoch)

Amalda (Gracilispira) morgani (Allan)

Ancillus olsoni n.sp.

Eoturris complicatus (Suter)

Cordieria rudis (Hutton)

The highest microfaunal sample collected by Srinivasan (1966), from 16 ft (4.9 m) above the cemented band, is from the lower part of the Tahu Member (A.R. Edwards, oral comm.). It yielded a small Kaiatan microfauna, including Pseudoglobоquadrina primitiva, indicating that it lies within Srinivasan's Gaudryina reussi Zone.

5. The concretions capping the Tahu Member are overlain by 7 m of soft, flaky-weathering siltstone that is greenish-grey when fresh but weathers light to medium grey (dry). Glauconite content varies throughout the unit but is generally much lower than in the underlying units. A band of moderately cemented concretions 7-8 cm thick is present 4.5 m above the base. Macrofossils are locally common but badly crushed and of low diversity, and include Saccella semiteres, Pseudoportlandia tahuia, Parvamussium sp. and Dentalium sp. This siltstone, the highest unit of the Waihao Greensands at McCullough's Bridge, is here named the Highcliff Siltstone Member after "Highcliff" station, a short distance upstream from McCullough's Bridge.

This unit has not been sampled closely for microfossils, but a sample from the top of the siltstone has yielded a Kaiatan microfauna (N. de B. Hornibrook pers. comm.).

6. The Highcliff Siltstone is overlain sharply and evenly by an off-white, moderately glauconitic, moderately hard limestone, 2.5 m of which is exposed in this section, assigned by Riddolls (1966: 84) to his Waikakahi Formation; earlier workers regarded it as the basal unit of the Waihao Limestone. A Whaingaroan microfauna has been collected from the base of the limestone, indicating that Runangan is

missing from this section (N. de B. Hornibrook, pers. comm.).

3. SECTIONS UPSTREAM FROM McCULLOUGH'S BRIDGE

Exposures of Waihao Greensands between McCullough's Bridge and Waihao Forks are rather discontinuous, and those that do occur are mostly submerged except when the river is low. Except for a tuff bed which is exposed prominently at two localities in the bed of the Waihao River (Kapua Tuffs, see below), the beds are light to medium grey, slightly to moderately glauconitic, calcareous siltstones, here included in the Highcliff Siltstone Member. The total thickness of this unit (including that portion exposed in the McCullough's Bridge section) is about 25 m.

Stratigraphic relationships within the Highcliff Siltstone are somewhat puzzling. As noted above, the member is Kaiatan at the top in the McCullough's Bridge section and is directly overlain by Whaingaroan limestone; a Runangan microfauna, however, has been collected from siltstone exposed near the head of a small gully about 100 m to the SW (N. de B. Hornibrook, pers. comm.). Siltstones with a thin tuff bed (presumably Kapua Tuffs) at the lower end of the gully have yielded a Kaiatan microfauna including Gaudryina reussi Stache, Sphaeroidina variabilis Reuss and Globigerina linaperta Finlay. Tuffs are not present in the McCullough's Bridge section.

A drill-hole sunk in March 1970 by Geophysics Division, DSIR, near the core of the shallow syncline 300 m upstream from McCullough's Bridge, penetrated about 14 m of siltstone before reaching Kapua Tuffs, but although the top of the hole must have been within the top 2-3 m of the Highcliff Siltstone, no Runangan was encountered (N. de B. Hornibrook, pers. comm.). Presumably any Runangan

sediments deposited in the Waihao district were largely removed by erosion before deposition of the Waikakahi Formation. The folding that produced the shallow syncline in the Waihao Greensands does not appear to have affected the Arno Limestone, though the large-scale cross-bedding in the latter unit makes it difficult to be certain. If so, the folding, accompanied by erosion, must have taken place during late Runangan to early Whaingaroan times. The Waikakahi Formation itself is not known west of Pinnacle Gully, and in Leslie's Gully 4.5 km NW of McCullough's Bridge, Waitakian greensand at the base of the Arno Limestone directly overlies Waihao Greensands (Riddolls 1966: 53, 58). This suggests that either (a) the western part of the Lower Waihao Basin was a topographic high that escaped sedimentation from at least Kaiatan to Duntroonian, or (b) the Waikakahi Formation was originally much more widespread but was locally removed by post-Whaingaroan erosion (i.e. during the Duntroonian).

Kapua Tuffs. This name was introduced by Riddolls (1966a: 39) for a bed of dark grey, calcareous, basaltic tuffs interbedded with siltstones of the Highcliff Siltstone and exposed prominently at two localities in the Lower Waihao River - (a) the type locality, c. 200 m upstream from McCullough's Bridge where it forms low rapids (Text fig. 4) and (b) some 600-800 m further upstream where it forms a broad shelf in the riverbed. There is also a minor exposure in a small gully near McCullough's Bridge (see above). The unit is 3 m thick at the type locality but only 1.5-2 m thick at the upstream outcrop. Riddolls (1966: 39) treated Kapua Tuffs as a member of the McCullough Formation, but for the purposes of this study it is regarded as a bed within the Highcliff Siltstone Member.

Text fig. 4. Gently dipping Kapua Tuffs exposed in bed of Waihao R. c. 200 m upstream from McCullough's Bridge. Glauconitic siltstone of the Highcliff Siltstone Member is exposed in the banks and bed of the stream upstream and downstream from this outcrop.

The existence of beds of volcanic origin in the Waihao Greensands seems to have escaped the notice of all geologists prior to Riddolls (1966), which is very surprising considering the prominence of the two main outcrops. Probably the tuffs became exposed as the result of artificial regrading of the riverbed downstream from McCullough's Bridge in 1961.

Bedding in the Kapua Tuffs is indicated by slight differences in coarseness and colour and by thin sheets of calcite about 5 mm thick. Bedding is even for the most part, but is locally strongly contorted, indicating subaqueous slumping. Bioturbation has produced mottling in some places, but the most spectacular evidence for the activity of burrowing organisms is afforded by subhorizontal forked tubular structures up to 30 mm in diameter and wholly or partly filled with calcite crystals that have grown centripetally from the walls.

Shelly macrofossils (known so far only from locality b) are very sparse and include molluscs and rare corals, brachiopods, crab chelae and an isopod (identified by D.F. Hurley, N.Z. Oceanographic Institute, as Cirrolana n.sp.). The molluscs have surface sculptural detail beautifully preserved but tend to become decorticated rather readily during extraction. The most common species are:

Fustiaria (Gadilina) maoria n.sp.

Zeminolia kapuaensis n.sp.

Dicroloma zelandica Marshall

Austrofusus bicarinatus (Suter)

Cordieria rudis (Hutton)

Superstes marshalli Finlay & Marwick

Spiratella kapuaensis n.sp.

Of these molluscs Z. kapuaensis is by far the most abundant species, the others being only moderately common by comparison. The molluscan fauna differs both qualitatively and quantitatively from that of the Tahu Member in a number of respects, although 26 species are common to the two faunas, viz:

(1) Bivalves, which are numerically important members of the Tahu Member fauna, are very rare in the Kapua Tuffs. Only 5 species were recorded from the latter unit in the present study compared with 32 from the Tahu Member.

(2) Archaeogastropods are very important members of the molluscan fauna in the Kapua Tuffs but are quite rare in the Tahu Member.

(3) The families Epitoniidae, Muricidae, Fasciolariidae, Cancellariidae and Pyramidellidae are at least moderately well represented in the Tahu Member but are unknown or poorly represented in the Kapua Tuffs.

(4) Pteropods are considerably more common in the Kapua Tuffs than in the Tahu Member.

(5) Many species that are common in the Tahu Member are rare or unrecorded from the Kapua Tuffs, e.g. Saccella semiteres (Hutton), Austrotindaria delli n.sp., Limopsis waihaoensis Allan, Notocorbula allani n.sp., Dentalium (Fissidentalium) waihaoense n.sp., Carinacca waihaoensis (Suter), Lathyrulus fraudator n.sp., Amalda (Gracilispira) morgani (Allan) and Eoturris complicata (Suter).

Some of these differences may merely reflect our comparatively poor knowledge of the Kapua Tuffs fauna, but most of them are probably due to environmental differences particularly in depth of deposition (see below) and substratal characters. The Kapua Tuffs are dated as

Kaiatan on foraminiferal evidence, so age differences are considered to be of minor importance.

The origin of the pyroclastic material in the Kapua Tuffs is uncertain; the nearest known volcanic vents of Kaiatan-Runangan age are in the Oamaru district about 35 km to the south (Gage 1957: 33-9).

CHAPTER III

PALEOECOLOGY

1. DEPTH OF DEPOSITION

(1) Tahu Member

A major problem in elucidating the depositional environment of the Tahu Member (and the other beds at McCullough's Bridge) is that most of the genus-group taxa present have no living representatives in New Zealand waters, although several survive in Australian seas and elsewhere. Nonetheless, the remaining forms give fairly consistent evidence for the probable depth of deposition, if it is assumed that they had similar ecological requirements to those living species assumed to be most closely related to them. In Table 2 molluscs from the Tahu Member which seem to have close relatives amongst living New Zealand species, are listed together with the corresponding Recent form and its depth range. Species marked with an asterisk (*) are relatively common in the Tahu Member; the others are uncommon to rare. If the depth ranges for the species of Austrotindaria, "Paramendax" and Waimatea are omitted, the remaining species are compatible with a depth of deposition of roughly 100-200 m (but possibly considerably deeper). The figure for "Paramendax" n.sp. is for a single trawl which cannot indicate its depth range. The Austrotindaria so common in the Tahu Member is certainly similar to the bathyal species A. flemingi but it is even closer to a species that is abundant in a Bortonian shellbed (GS 9957) in the South Branch, Waihao R. near "Pentland Hills", where it is associated with common tellinids, venerids (Dosinia,

Fossil species	Living species	Depth range (nearest 5 m)	Reference
Ennucula whatu n.sp.	*E. strangei* (A. Adams)	5 - 605	Dell 1956
* *Saccella semiteres* (Hutton)	*S. bellula* (A. Adams)	10 - 285	" "
* *Austrotindaria delli* n.sp.	*A. flemingi* Dell	475 - 605	" "
Nemocardium (Pratulum) semitectum Marwick	*N. pulchellum* (Gray)	10 - 550	" "
Cuspidaria cf. *fairchildi* Suter	*C. fairchildi* Suter	110 - 605	" "
* *Dentalium (Fissidentalium) waihaoense* n.sp.	*D. zelandicum* Sowerby	20 - 550	" "
"Paramendax" disparilis n.sp.	*"Paramendax"* n.sp.	490 - 540	A.G. Beu, pers. comm.
* *Tanea praeconsors* (Finlay)	*T. zelandica* (Quoy & Gaimard)	0 - 605	Dell 1956
* *Globisinum elegans* (Suter)	*G. drewi* (Murdoch)	75 - 550	" "
Austrosassia cyphoides (Finlay)	*A. parkinsonia* (Perry)	0 - 100	A.G. Beu, pers. comm.
Cirsotrema zitteli n.sp.	*C. zelebori* (Dunker)	0 - 200	Dell 1956
Poirieria aff. *primigena* Finlay	*P. zelandica* (Quoy & Gaimard)	20 - 200	" "
Coluzea climacota (Suter)	*C. spiralis* (A. Adams)	75 - 200	" "
* *Austrofusus separabilis* n.sp.	*A. glans* (Roeding)	0 - 605	" "
* *Waimatea inconspicua* (Hutton)	*W. obscura* (Hutton)	0 - 35	Cernohorsky 1970
* *Amalda (Gracilispira) morgani* (Allan)	*A. novaezelandiae* (Sowerby)	0 - 255	Dell 1956
Odostomia waihaoensis n.sp.	*O. corpulentoides* Dell	220 - 605	" "

Table 2. Selected molluscs from Tahu Member, McCullough's Bridge, with related living New Zealand species and their recorded depth ranges. Species marked with an asterisk * are moderately common in the Tahu Member, the others are uncommon to rare.

Costacallista) and corals (Oculina, Dendrophyllia, etc.). The faunal content, lithology and general stratigraphic setting (lower part of a transgressive sequence) all indicate deposition in quite shallow waters, probably in the inner neritic zone, so Austrotindaria of the flemingi group evidently has not always been restricted to bathyal depths.

The only Recent species of Waimatea, W. obscura (Hutton) lives on gravel or sand substrate or intertidally under stones, in depths of 0-36 m (Cernohorsky 1970: 125); fossil species, however, almost certainly inhabited a greater range of habitats, extending into considerably deeper waters. As evidence of this may be cited the occurrence together of Waimatea inconspicua (Hutton) with a species of the bathyal genus Calliotropis in a Kaiatan collection (GS 3301) from near Inangahua, and of W. costulosa (Marwick) with species of Zealeda, Tindaria /Nuculana (Jupiteria) kapua Marwick/ and Micantapex at Opoitian localities in Hawke's Bay (see data in Marwick 1965).

Additional evidence for moderately deep conditions for deposition of the Tahu Member comes from genera lacking Recent New Zealand representatives but surviving in other parts of the world. Some of these are discussed below.

(a) Pelecypoda. Limopsis: L. waihaoensis (Allan), one of the commonest bivalves in the Tahu Member, resembles the southern Australian species L. penelevis Verco in size, shape and weakness of external sculpture. Cotton (1961: 48) records L. penelevis from depths of 167-549 m.

Eucrassatella: The specimens of Eucrassatella collected from the Tahu Member and from the Kapua Tuffs are

small, almost certainly subadult shells. Verco (1907) recorded "small and poor" specimens of E. donacina (Lamarck) from depths of 73 and 183 m in South Australia and normal sized shells from 27-37 m (Verco 1905) (see Darragh 1965: 96).

Notocorbula: Iredale (1930: 405) did not give any depth information when he described N. vicaria, the type species of the genus, but the holotype is from Sydney Harbour, presumably from moderately shallow waters. The living South Australian species N. iredalei (Cotton) is recorded "down to 22 fathoms" (i.e. 40 m) by Cotton (1961: 300). New Zealand Cenozoic species seem to have lived in a considerable range of depths, from inner neritic to bathyal regions, judging by material in Geological Survey collections.

(b) Scaphopoda. The following depth ranges for scaphopods represented in the Tahu Member are taken from Habe (1964).

Fustiaria (Gadilina):	100-1886 m
Entalina:	200-1300 m
Cadulus (Polyschides):	50-1400 m
C. (Gadila):	0-1886 m

(c) Gastropoda. Benthastelena: B. turua n.sp. is similar to the type species B. katherinae Iredale, described from 110 fathoms (201 m) east of Sydney and recorded from "the Continental shelf, in the deeper water" by Iredale (1936: 286).

Ancillus: The common Ancillus olsoni n.sp. resembles the species described by Schepman (1911: 258) from 1301 m, Makassar Strait, Indonesia, as Ancilla abyssicola.

Gemmula: The living Indo-Pacific species of Gemmula recorded by Powell (1964: 243-64) have an extreme depth range of 4-1234 m, but most of the records are from depths greater

than 100 m.

Marshallena: Marshallena neozelanica (Suter), the only known New Zealand species of the genus, is very similar to the Recent Indo-Pacific M. philippinarum (Watson), recorded by Powell (1969: 369) from depths of 100-1100 m. (Several other New Zealand fossil turrids, some of them from shallow water beds, have been referred to Marshallena, but all are assigned to other genera elsewhere in this dissertation).

With the exception of Ancillus, the taxa discussed above suggest a depth of deposition of roughly 150-200 m; i.e. in broad agreement with the depth (100-200 m) indicated by genera with surviving New Zealand representatives. This corresponds to the depths on the outer part of the present day continental shelf. Apparent anomalies (e.g. Ancillus) may be due to misidentification at the generic level or to changes in habitat of the taxa concerned since the late Eocene, or to inadequate bathymetric data.

(2) Kapua Tuffs

As noted in the stratigraphic section, the molluscan fauna of the Kapua Tuffs differs both qualitatively and quantitatively from that of the Tahu Member. Differences in substrate probably account for part of this dissimilarity but a difference in depth of deposition may also be a contributing factor. Taxa which give some bathymetric evidence are discussed below.

Parathyasira: The type species of the genus, P. resupina Iredale, was described from 115-137 m off Port Kembla, N.S.W.; the recent New Zealand form, described as P. resupina neozelanica Iredale, from 201 m off Great Barrier Island. Dell (1956b: 166) gives a depth range of 46-549 m for P. neozelanica. Parathyasira verconis

Cotton and Godfrey from South Australia and Western Australia is recorded from depths of 91-366 m (Cotton 1961: 225).

Zeminolia: Z. kapuaensis n.sp., the most common mollusc in the Kapua Tuffs, is closer to Z. semireticulata (Suter) in size, sculpture and umbilical features than to the other Recent species. Z. semireticulata is recorded from 91 to 238 m (Dell 1956a: 168) but has also been found in a sample trawled from 490-540 m in the Papanui Canyon, Otago (ident. A.G. Beu).

Zetela: Z. vulcania n.sp. is not particularly close to either of the living New Zealand species, but is remarkably similar to "Solariella" albalitus MacNeil, 1960 (Pliocene, Okinawa). MacNeil (1960: 24) considered albalitus to be related to the Recent species S. amabilis Jeffreys, 1865, which was described from 155-175 m in the Shetlands (Jeffreys 1865: 300) and recorded by Dall (1889: 378-9) from depths of 350-1625 m in the Caribbean.

The above evidence is too scanty to give much indication of the probable depth of deposition of the Kapua Tuffs, except to suggest that it was at least as great as that inferred for the Tahu Member. Consideration of the regional geological history, on the other hand, indicates that the Kapua Tuffs were deposited under considerably deeper conditions.

Wellman (1953: 31-4) and Wilson (1955) have presented evidence for progressive marine transgression in the South Island, beginning in the late Cretaceous and persisting until the Oligocene. Its acme was probably in late Whaingaroan, when the rate of supply of terrigenous material to the sea dwindled almost to zero in some parts of Canterbury and the only sediments deposited were essentially biogenic (e.g., limestones, marls and chalks). This was presumably also the

period of maximum submergence. The stratigraphic succession in the Waihao district is in broad agreement with the regional evidence, passing from the quartzose, coal-bearing Pentland Hills Formation through the Lower Waihao Greensands which locally contain common marine macrofossils, up into the siltier, less fossiliferous units of the upper greensands (capped by the Highcliff Siltstone Member) and finally into the glauconitic marl (Waikakahi Siltstone) forming the basal unit of the Arno Limestone (see Table 1). If it is assumed that this sequence represents progressive submergence (apart from a brief stillstand suggested by the burrowed, cemented band at McCullough's Bridge and a period of folding and erosion prior to deposition of the Waikakahi Siltstone) then it seems likely that the Ngapuke Member was deposited under shallower conditions and the Highcliff Siltstone Member (including the Kapua Tuffs) under deeper conditions than the Tahu Member. This may be a somewhat over-simplified picture, however, as the well-developed slump structures in the Kapua Tuffs suggest that they may have been originally deposited in somewhat shallower waters than the immediately underlying and overlying siltstones. It may be that the Kapua Tuffs were emplaced in their present geographic position after sliding a considerable distance along the sea floor.

2. SALINITY

All the extant genus-group taxa recorded from the Ngapuke, Tahu and Highcliff Members are normal, euhaline forms, and so, probably, are those without living representatives. The presence of the oyster Pycnodonte in the lowest, unnamed unit at McCullough's Bridge suggests that this too was probably deposited under conditions of normal salinity. Stenzel (in Moore 1971: N1040) notes that the two living

pycnodontine genera (Hyotissa and Neopycnodonte) both live in euhaline waters and concludes that the fossil gryphaeids probably had similar salinity preferences, there being no known case where they are associated with fossils or sediments indicative of brackish waters.

3. TEMPERATURE

The molluscan genus-group taxa in the Tahu Member that have living representatives can be divided broadly into the following groups:

(1) Taxa which are virtually New Zealand-wide in distribution and live today at the latitude of McCullough's Bridge ($44^{\circ}50'S$) or further south. These include: Ennucula, Saccella, Austrotindaria, Nemocardium (Pratulum), Cuspidaria, Dentalium (Fissidentalium), Brookula, Lissotesta, Submargarita, Lironoba (Nobolira), Zeocolpus, Tanea, Globisinum, Cirsotrema, Poirieria, Coluzea, Liratilia, Austrofusus, Amalda (Gracilispira), Turbonilla and Odostomia.

(2) Taxa living today in New Zealand only in the northern part of the North Island: Verticordia (Spinosipella), Gegania, Austrosassia, Pterynotus, Waimatea, Conus (s.l.) and Syrnola. Most of these taxa also occur living in southern Australian waters.

(3) Taxa with no known living New Zealand representatives, but recorded from southern Australia (i.e. N.S.W., Victoria, Tasmania, South Australia, southern Western Australia) and further north: Limopsis, Sarepta, Eucrassatella, Benthastelena, Cheilea, Lachryma, Sassia and Opalia.

(4) Taxa that are typically Indo-Pacific (including northern Australian) in distribution: Fustiaria (Gadilina), Colubraria, Ficus, Gemmula and Marshallena. /Gemmula does occur rarely in N.S.W. but

all other records are from the Indo-Pacific and Caribbean-Panamic regions (Powell 1964: 243)/.

The simplest inference to be drawn from the above distributional data is that the molluscs in the Tahu Member lived in considerably warmer waters than prevail today off the South Canterbury coast, where winter surface temperatures are only 10-11°C and bottom temperatures (at 70-80 m) about 10° (Garner 1969). The presence of the taxa in categories 3 and 4 indeed suggests temperatures above those recorded in northernmost New Zealand /winter surface temperatures of 15-16°C, bottom temperatures (130-140 m) of 13-15.5°C at North Cape (lat. 34°S) (op. cit.)/. A closer model is provided by northern N.S.W. where tropical waters from the north impinge on the more temperate waters of southern Australia and some intrusion of typically Indo-Pacific forms can be expected (e.g. Gemmula, see above). Winter surface temperatures in this region (about 32°S latitude) are 17-18°C and the mean bottom temperature (at 200 m) is 16°C (Ekman 1953: 197). The relative scarcity of typical Indo-Pacific forms (in terms of number of taxa rather than of individuals) in the Tahu Member suggests that conditions were subtropical rather than tropical (in the sense of Ekman 1953: 3).

The conclusion that subtropical conditions prevailed in South Canterbury in the Kaiatan strictly applies only to the short period of time represented by the Tahu Member (i.e. early Kaiatan). Other workers who have written on the question of Upper Eocene temperatures in New Zealand have generally considered the Kaiatan in toto or in conjunction with the Runangan, procedures that seem ill-advised in the light of the strong evidence for a significant climatic change in the period late Kaiatan-early Whaingaroan, assembled by Edwards

(1968b). Also there has been a tendency to consider climates in New Zealand as a whole rather than in some limited geographic area. These points are taken into account in the following discussion where previous work is looked at critically.

4. REVIEW OF EVIDENCE FOR TEMPERATURES IN THE ARNOLD SERIES

Hornibrook (1953: 438) suggested that the reappearance of the larger foraminifer Asterocyclina (following its apparent absence from the Middle Eocene), accompanied by several warm-water forms (Carpenteria, Asterigerina, Amphistegina, Halkyardia and Peneroplis) was evidence for tropical conditions in the Kaiatan and Runangan. In the North Otago-South Canterbury area, Asterocyclina is now known from a Bortonian (or older) horizon at the base of the Waihao Greensands in the South Branch, Waihao River (Cole 1967: 10-11, Riddolls 1966) and from Runangan limestone at Fortification Hill and Maheno, North Otago (Cole 1967: 6-10). There are no Kaiatan records of the genus from the New Zealand mainland, though a Kaiatan age is possible for one of the Chatham Islands occurrences (Scott in Hay et al. 1970: 37). Of the other genera mentioned by Hornibrook, Peneroplis is known only from the Omotumotu beds of Westland (Runangan) and is therefore not directly relevant to discussions on Kaiatan climate, but the remaining forms are all indicated by Hornibrook (1968b: 51) as making their first appearance at the base of the Kaiatan. Asterigerina and Halkyardia are both known from the early Kaiatan (Reticulofenestra bisecta Zone of Edwards 1971) at Ten Mile Bluff, Westland (Hornibrook 1961: 167 and Geological Survey files) but in the Oamaru district Asterigerina is first recorded from the Waiareka Tuffs (late Kaiatan or possibly early Runangan) and Halkyardia is

known only from the Maheno Marl (Runangan) (Hornibrook 1961: 166-7). Their absence from older horizons in the Oamaru district may be due to the lack of suitable lithofacies or to climatic differences between the west and east coasts of the South Island in the Upper Eocene.

More important is the distribution of Amphistegina which makes its first appearance in New Zealand in the Waiareka Tuffs at Lorne, North Otago (i.e. late Kaiatan or early Runangan) and is thereafter present through most of the Cenozoic (Hornibrook 1961: 168; 1968a). This is especially significant as the southern limit of the genus in the Pacific today roughly coincides with the 20°C mean surface isotherm, which lies at about the latitude of Sydney (34°S). The absence of Amphistegina from early Kaiatan beds (including the Tahu Member) may be due to (a) cool conditions prevailing at this time (which is at variance with the molluscan evidence), (b) deposition at depths greater than the lower limit of Amphistegina (about 175 m for living species - Hornibrook 1968a: 11) which may be true for the Tahu Member though probably not for all known Kaiatan sediments, or (c) to some other ecological factor. It is by no means certain, of course, that the fossil species of Amphistegina had similar ecological requirements to the living species; in this respect it is worth pointing out that Amphistegina is common in the McDonald Limestone (Whaingaroan) in North Otago despite the cool conditions that apparently prevailed at that time. (Oxygen isotope measurements of two samples of shallow water McDonald Limestone of early Whaingaroan age indicate bottom temperatures of 13-5 and 14.4°C - Devereux 1967: 999).

Jenkins (1968a: fig. 1) constructed a paleotemperature graph

for the New Zealand Cenozoic based on the stratigraphic distribution of planktonic Foraminiferida. He concluded (p. 34) that the "Middle-Upper Eocene faunas were not fully tropical except possibly for two short peaks indicated by invasions of the exotic species of Hantkenina". On his graph he puts these peaks in the late Bortonian and at the Kaiatan-Runangan boundary. The former peak is based on the occurrence of Hantkenina australis Finlay (described from Hampden, North Otago) in the Bortonian and H. alabamensis Cushman in the early Runangan (including Port Elizabeth, Chatham Islands and possibly Maheno, North Otago). Srinivasan (1965: 186) also records H. alabamensis from the late Kaiatan of Port Elizabeth. There are no records of the genus from the early Kaiatan.

In another paper, Jenkins (1968b) used a different approach to the problem of paleotemperatures, viz. comparing faunal diversity by counting the number of species-group taxa of planktonic Foraminiferida in each planktonic foraminiferal zone. Jenkins apparently combined the data for New Zealand as a whole rather than for a more restricted geographic area, but the resulting graph probably gives some idea of general climatic trends on Jenkins' assumption that diversity increases with temperature. His graph has a marked peak (about 26 taxa) in the mid-Bortonian (Globigerapsis index index Zone), a drop to 20 taxa at the Bortonian-Kaiatan boundary, a rise to 23 taxa in early Kaiatan (Globorotalia inconspicua inconspicua Zone), a drop to 14 taxa in late Kaiatan (lower part of Globigerina linaperta Zone), followed by a rise to 18 taxa in mid-Runangan (upper part of G. linaperta Zone). If these results are meaningful guides to paleotemperatures, they are the only indication that the late Kaiatan was significantly cooler than the early Kaiatan.

From his study of Kaiatan-Runangan Foraminiferida, chiefly from Port Elizabeth and Cape Foulwind, Westport, Srinivasan (1965: 303) came to the following conclusion regarding Upper Eocene climates in New Zealand. "During most of Upper Eocene time the climate was warm-temperate. During late Kaiatan and early Runangan time the temperature rose to sub-tropical. New Zealand waters never attained a tropical temperature during those times as most larger Foraminifera characteristic of the tropical regions did not reach New Zealand".

Squires (1958: 22) concluded that the scleractinian coral fauna recorded from the Arnold Series indicated temperatures of between 50 and 60°F (10-15.5°C) which he noted were similar to temperatures found today off Otago, that there was no evidence for latitudinal zonation in the Bortonian and that Kaiatan-Runangan temperatures were probably similar to those in the Bortonian. Squires gives temperature ranges for 10 genus-group taxa that have representatives in the Arnold Series; one of these /Balanophyllia (Eupsammia)/ has a temperature range (28-34.5°C) that lies well outside the range suggested by the other forms. B. (Eupsammia) hectori Tenison-Woods occurs locally in great profusion at a number of Bortonian localities in South Canterbury but has not been recorded from Kaiatan or Runangan beds. The other taxa listed by Squires come from a number of different horizons and lithofacies and cannot be considered as typical of the Arnold Series as a whole. The following genus-group taxa are recorded from the Tahu Member:

Notocyathus (s.str.)	(No temperature range available)
N. (Paradeltocyathus)	9 - 23°C
Conocyathus	15°C
Flabellum	2 - 27.5°C

The temperature ranges are taken from Vaughan and Wells (1943: 52-5) and apparently refer to bottom rather than surface temperatures. Vaughan and Wells (p. 57) note that temperature data for ahermatypic corals are few and imprecise, but the small faunule recorded above suggests temperatures consistent with the molluscan evidence (bottom temperature of about 16°C).

Keyes (1968) re-examined the scleractinian coral evidence for Cenozoic paleotemperatures and concluded that Arnold Series faunas indicated surface temperatures of between 20 and 25°C. He suggested that the Bortonian (with the apparently hermatypic coral Madracis) was somewhat warmer than the Kaiatan and Runangan.

From his study of nannoplankton distribution, Edwards (1968a) postulated a gradual rise in surface temperature from about 14°C (at latitude of Wellington) to a peak of 20°C in the Kaiatan, followed by a drop through the Runangan to about 14°C in the Whaingaroan (present mean surface temperature at Wellington is about 15°C). His graph is based on data from sections throughout the country, but in a second paper (Edwards 1968b) he considered the evidence from nannoplankton, diatoms, forams, corals, molluscs and oxygen isotope measurements for late Kaiatan-early Whaingaroan climates in North Otago. The various lines of evidence are in broad agreement in indicating warm conditions in late Kaiatan-early Runangan followed by a pronounced cooling in late Runangan and early Whaingaroan, but there is some discrepancy between the planktonic and benthonic fossils as to just how warm the climate became. In general, the benthonic forms indicate considerably warmer conditions (marginally tropical) than the planktonic forms (which indicate subtropical temperatures).

Paleobotanical evidence for terrestrial climates in the Arnold

Series is somewhat at variance with the evidence for marine temperatures from other fossil groups. Couper (1960: 33) suggested warming from Mata Series (late Cretaceous) up to Runangan when pollen of Nothofagus (brassi group), Proteaceae and Cupanieidites become common, indicating "at least subtropical if not tropical conditions". McQueen et al. (1968: 52), however, noted that in the Bortonian and Kaiatan Nothofagus of the "fusca" group was abundant in Southland while podocarps, Cupanieidites and Dysoxylum were present in Waikato district, indicating climates very similar to those found today in the areas concerned. An "abrupt change" from dominance of Nothofagus of the "fusca" group to the "brassi" group was taken as evidence for a rapid increase in temperature in the Runangan with a climate "much warmer than that of the present day". The paleotemperature graph given by McQueen et al. (fig. 1, p. 52) indicates sea-level temperatures in Bortonian-Kaiatan of 15°C, rising to 20°C in the Runangan. [The mean temperature at sea-level in the region of Cook Strait is about 12.5°C (Kidson 1931)].

Fell (1954) did not comment directly on Upper Eocene climates in New Zealand, but he described a species of the warm-water cidarid genus Eucidaris from a locality on Chatham Island now known to be of Arnold Series age (Scott in Hay et al. 1970: 37). Other records of the genus are from the Whaingaroan of North Otago, Duntroonian of Waitaki Valley and Waitakian of Southland (Fell 1954: 46-8), from the Bortonian of Waihao Valley and possibly from the Runangan of Oamaru district. Living species of Eucidaris do not occur in waters with a winter surface temperature less than 15°C (Fell 1954: 21), so it appears that the 15° winter isotherm lay well to the south of its present position (about 38°S on east coast of North Island - Garner 1962) for much of Arnold and Landon Series time.

Devereux (1967, 1968) used oxygen isotope ratio measurements on marine fossils to construct a paleotemperature curve for the New Zealand Cenozoic. Unfortunately his curve is based on a mixture of results from both planktonic and benthonic groups (indicating surface and bottom temperatures respectively), and therefore gives only a general idea of climatic trends. In the Arnold Series the value of the graph is further diminished by the rather spotty sampling. The only Bortonian sample is from the mouth of Kakaho Creek, Hampden, assigned by Edwards (1971: 399) to the top of his Reticulofenestra hampdenensis Zone or the base of the overlying Discoaster distinctus Zone. Devereux (1968: 1000) obtained an isotopic temperature of 19.1°C for a mixture of species of the benthonic foraminifer Robulus and 17.2°C (average of two samples) for another benthonic species, Vaginulinopsis hochstetteri (Stache). The Bortonian beds at Hampden were probably deposited in moderately deep waters (perhaps 200 m or more) so surface temperatures would have been several degrees higher than bottom temperatures. In general, the difference between surface and bottom temperatures increases with increase in surface temperature, so it is difficult to know what correction should be made in this case. However, the surface temperature is likely to have been more than 20°C.

No early Kaiatan samples were analysed by Devereux, but specimens of Robulus from "mid"-Kaiatan mudstone at Burnside Quarry, Dunedin (near top of Chiasmolithus oamaruensis Zone according to Edwards 1971: 404) gave an isotopic temperature of 12.3°C (Devereux 1968: 1000). Hornibrook (in Hamilton 1958: 229-30) stated that the Foraminiferida in the Burnside Mudstone suggested deposition of the Burnside Mudstone in depths "of the order of 100 fathoms", so surface temperatures were probably at least 15°C. A sample from higher in

Stage	Planktonic Foraminiferal Zone	Nannoplankton Zone
Whaingaroan		Blackites rectus
	Globigerina brevis	
Runangan		Reticulofenestra oamaruensis
	Globigerina linaperta	Discoaster saipanensis
		Isthmolithus recurvus
Kaiatan		Chiasmolithus oamaruensis
	Globorotalia inconspicua inconspicua	Reticulofenestra bisecta
		Discoaster tani nodifer
		Discoaster distinctus
Bortonian	Globigerapsis index index	Reticulofenestra hampdenensis
		Chiphragmalithus cristatus
Porangan		

Table 3. Planktonic foraminiferal zones and nannoplankton zones of Arnold Series (after Edwards 1971). Not to scale.

the Burnside Mudstone (Isthmolithus recurvus Zone - Edwards 1971: 405) was also analysed by Devereux; benthonic forams gave an isotopic temperature of 16.1°C, planktonic forams a temperature of 17.6°C.

Devereux's work indicates a climatic peak in the early Runangan in North Otago. A sample from Clark's Flour Mill, Maheno (Discoaster saipanensis Zone - Edwards 1971: 406) gave a bottom temperature of 19.1°C and a surface temperature of 21.0°C, whereas samples of bryozoan limestone, presumably of shallow-water origin, from higher in the Runangan, give bottom temperatures of 12.3-13.1°C (Devereux 1967: 999). It seems doubtful, however, that temperatures in the early Runangan were significantly higher than those in the Bortonian and it is unfortunate that other Bortonian samples were not analysed by Devereux.

Molluscan evidence for Cenozoic paleotemperatures has been discussed briefly by Fleming (1962) and in more detail by Beu (1966) and Beu and Maxwell (1968). Fleming (1962: 72) suggested that the appearance of Cypraeidae, Architectonica, Mitridae, Eocithara, Conidae and Gemmula in the Bortonian indicated "dominance of Malayo-Pacific dispersal avenues and subtropical climates". Beu (1966: 181) listed warm water molluscan genera from each of the Arnold Series stages and concluded that as only two definitely tropical genera were known from the Kaiatan, seas at that time were unlikely to be "truly tropical". His Kaiatan records were based on faunas from McCullough's Bridge and from Lorne, North Otago. In his temperature graph (p. 185) he indicated that subtropical conditions persisted throughout the Arnold Period (and indeed, the rest of the Eocene) in New Zealand.

Beu and Maxwell re-examined the molluscan evidence, attempting

to separate records of warm water taxa from the southern part of the South Island from those recorded only from the northern part of the North Island (i.e. Northland). They counted genus-group taxa of inferred Indo-Pacific origin recorded from each of the New Zealand stages, and also attempted to express these as a percentage of the total recorded molluscan fauna for each stage. 31 Indo-Pacific taxa were recorded from the Bortonian, 36 from the Kaiatan, and only 13 from the Runangan (fig. 1, p. 69). When these occurrences were expressed as percentages of the total fauna, however, the respective figures were 21, 25 and 37%. Beu and Maxwell interpreted these figures as evidence for warming from Bortonian to Runangan (fig. 4, p. 72) and postulated marginally tropical conditions in the South Island during the late Arnold times. It should be pointed out, however, that some of the records of Kaiatan-Runangan molluscs used by these authors were from localities on the west coast of the South Island, and so possibly from a warmer regimen than on the east coast. In the following discussion on molluscan evidence for Arnold sea-temperatures, the possibility of complications due to latitudinal differences is minimised by considering only those faunas recorded from North Otago and South Canterbury.

(1) Bortonian

Over the past few years, rich and largely undescribed molluscan faunas have been collected (first by Dr R.M. Carter and later by the writer) from shellbeds of presumed Bortonian age (though possibly somewhat older) in the South Branch Waihao River near "Pentland Hills" homestead. Taxa indicative of warm conditions include Arcidae (including ?Arcopsis), Spondylus, Plicatula (only definite New Zealand Tertiary record), Dimya, Rocellaria, Septifer

and Lithophaga (all earliest local records), Lucinidae (including Miltha), Veneridae (Callistotapes, Placamen), Liotina, Gegania, ? Psilaxis and Gemmula. Associated with these molluscs are radioles of Eucidaris and abundant corals /including species of Conocyathus, Dendrophyllia, Balanophyllia (Eupsammia), Oculina and the apparently hermatypic Madracis/.

Further east, in the lower Waihao Valley, the well-known "Waihao Downs" localities have yielded the following thermophilic forms - Rimella (the only New Zealand strombid), the harp shell Eocithara (Marwickara), Sassia, Granosolarium, Gegania and Gemmula. At McCullough's Bridge, the lower greensand is the source of the only record of Nemocardium s.str. from New Zealand, although the genus still lives at the Kermadec Islands.

The deep-water mudstones at Hampden Beach have also yielded a number of warm-water molluscs including Columbarium, Cypraeidae (two species), Ancillina, Conidae (two species), Marshallena and Gemmula (several species).

(2) Kaiatan

The only definite early Kaiatan molluscan fauna of any size is that recorded from the Tahu Member. As was concluded earlier, the composition of this fauna indicates at least marginally subtropical conditions. The molluscs recorded from the overlying Highcliff Siltstone at McCullough's Bridge are too poorly known to be of much use for paleo-ecological analysis, but the presence of the cypraeid ?Notoluponia (Notadusta) sp. suggests moderately warm waters.

The molluscan fauna from the Kapua Tuffs is still imperfectly known but as it includes Amygdalum (extinct in New Zealand but living in south-eastern Australia), Fustiaria (Gadilina) (considerably more

common than in the Tahu Member), Ficus, Gemmula and the pteropod Hyalocylis, it too is taken to indicate warm conditions. The well-known fossil locality at William's Bluff, Lorne, North Otago, possibly of similar age to the Kapua Tuffs, has yielded a rich molluscan fauna that includes such warm-water forms as Arca s.str., Arcopsis, Amygdalum, Bolma (=Incilaster, A.G. Beu, pers. comm.), Danilia, Gegania, Hipponyx, Colubraria, Sassia, Ficus, Pterynotus, ?Parviconus (very similar to the Victorian Miocene species Conus dennanti Tate) and Hyalocylis (more common here than at other localities).

(3) Runangan

Very few molluscan faunas of Runangan age have been collected anywhere in New Zealand. In North Otago only two localities have yielded faunas of any size - Trig M, Totara (early Runangan - A.R. Edwards, pers. comm.), and Bridge Point, Kakanui. The former locality has a number of genera (and in many cases, species) in common with Lorne, including Arcopsis, Bolma, Danilia, Hipponyx, Ficus and Hyalocylis. The Bridge Point fauna is less well-known but includes Arcopsis, Limea (Isolimea), Danilia, Ficus, a triviid that resembles Trivirostra and common Aturia. Bridge Point is also the type locality of Cardilona bensoni Marwick which is referrable to the verticordiid genus Pecchiolia; other records of the genus are from the Upper Eocene to Miocene of Europe.

The molluscan evidence suggests that Bortonian seas were fully subtropical and possibly marginally tropical in North Otago-South Canterbury, that there was some cooling in early Kaiatan times (though temperatures remained at least marginally subtropical), but that by late Kaiatan-early Runangan times temperatures were about as

high, if not quite as high, as in the Bortonian. This is in at least broad agreement with the evidence from oxygen-isotope measurements (although more analyses of Bortonian samples would be desirable) and does not conflict with the conclusions of Jenkins (1968a) based on planktonic Foraminiferida.

A cooling at the end of the Bortonian may explain why certain molluscan taxa (i.e. Sigaretotrema, Priscoficus, Fascioplex, Athleta and Speightia) became extinct in New Zealand at about this time.

CHAPTER IV

COMPOSITION OF MOLLUSCAN FAUNAS FROM TAHU MEMBER AND KAPUA TUFFS

The molluscan faunas recorded from the Tahu Member and Kapua Tuffs cannot be considered in total isolation but must be treated merely as parts of the large, complexly changing and still poorly understood plexus that makes up the New Zealand Cenozoic molluscan fauna. Some taxa (primarily at the specific level) are known only from McCullough's Bridge, others are recorded from other mid-Cenozoic faunas, and yet others are known from virtually throughout the Cenozoic. In this section the recorded taxa are discussed individually in an attempt to place these faunas in a broader perspective.

1. PELECYPODA

Nuculidae. This family is poorly represented in both the Tahu Member and the Kapua Tuffs compared with most Cenozoic faunas that the writer has examined. The new genus Nanonucula, present in the Tahu Member, is otherwise definitely known only by an undescribed species from Otaian beds at Parengarenga Harbour and by Recent Australian species. Ennucula, known from both units, has a long though sporadic record extending from Wangaloan up to the present day. The genus is very conservative and the Kaiatan species is very similar to the Recent E. strangei (A. Adams).

Nuculanidae. Nuculanids compensate for the nuculids in both diversity and abundance in the Tahu Member. Saccella semiteres (Hutton), one of the most common molluscs at McCullough's Bridge, is an early member of a group that is well-represented in the Cenozoic

and survives today as S. bellula (A. Adams). Pseudoportlandia tahuia (Marwick), also present in the Kapua Tuffs, is the Kaiatan representative of a distinctive group of large nuculanids, restricted in New Zealand to the Arnold Series, though the type species is from the Miocene of Jamaica. P. tahuia is very similar to the Hampden (Bortonian) species P. solenelloides (Marshall). Austrotindaria delli n.sp., another common species, is very similar to the living archibenthal species A. flemingi Dell and has a close relative in Bortonian shellbeds in the upper Waihao valley. Ledaspina, common in deep water faunas from the New Zealand Neogene and apparently still living at abyssal depths in the Tasman Sea, makes its first known appearance in the Tahu Member. Of the remaining nuculanids, Ledella, Jupiteria and Yoldiella are generally well-represented in younger faunas and live today in neritic and bathyal waters around New Zealand, while Sarepta, which has a rather sporadic fossil record, is no longer living in New Zealand but survives in south-east Australia.

The proportion of protobranchs (i.e. in this case nuculids and nuculanids) in the bivalve fauna from the Tahu Member is unusually high. Of 32 species of Pelecypoda recorded in this dissertation, 10 (i.e. 31%) fall into this category. Nicol (1972) found that in Recent shallow water (presumably neritic) faunas from the Northern Hemisphere, protobranchs comprise only 1 to 7% of tropical and warm-temperate bivalve faunas, increasing to 23% in Arctic waters. (In Antarctic faunas, protobranchs comprise only 13% of the total bivalve fauna). Four Eocene faunas (presumably from North America) gave an average of 13% protobranchs and one Miocene fauna (from Astoria, Oregon) has an unusually high figure of 25% protobranchs (Nicol 1972). Nicol notes that "at great depths (2000 meters or more) the proto-

branchs comprise at least 35 per cent of the total pelecypod fauna".

The Tahu Member was deposited neither under polar conditions nor at abyssal depths, so the high proportion of protobranchs is difficult to explain. It should be pointed out, however, that the total bivalve fauna is rather small and cannot seriously be claimed to be typical of the early Kaiatan even within the geographically limited North Otago-South Canterbury area. Ecological factors other than temperature and water depth almost certainly have some influence on protobranch diversity, e.g. substratal characteristics including sorting and mean grain size.

Arcidae. The only arcid recorded from the Tahu Member is the small Bathyarca bellatula Marwick, originally described from Hampden (Bortonian) and differing markedly from other New Zealand species of Bathyarca in its strongly crenulated margins and prominent sculpture. Its true affinities may be with the Noetiidae.

Cucullaeidae. Specimens of Cucullaea from the Tahu Member are small and probably immature, but they are tentatively assigned to C. (Latiarca) waihaoensis Allan, originally described from Bortonian of Waihao Downs. This species is an early member of a group that was widespread in neritic faunas throughout New Zealand until late Miocene times.

Limopsidae. Limopsis waihaoensis Allan, one of the most common molluscs in the Tahu Member, belongs to a small group of species occurring sporadically from Bortonian to Opoitian in New Zealand. They may represent a deeper-water group than the comparatively large species of Limopsis which usually predominate in New Zealand faunas. Limopsis penelevis Verco (Recent, South

Australia) may be related. Notolimopsis hampdenensis (Marshall), rare at its type locality (Hampden) but quite common in the Tahu Member, is the earliest known species of this distinctive endemic genus which persists until the Altonian in North Otago and South Canterbury (Maxwell 1969: 167).

Philobryidae. Lissarca (=Austrosarepta) makes its first known appearance in the Tahu Member; the genus has a sporadic record in the New Zealand Cenozoic.

Mytilidae. The only representative of this family is a small specimen of Amygdalum from the Kapua Tuffs. Amygdalum occurs sporadically from Bortonian to Castlecliffian in New Zealand (Fleming 1959a) and survives in south-east Australian waters.

Pectinidae. No less than three species of Parvamussium are recorded from the Tahu Member. The most common species is probably related to P. vafer (Marwick) and similar species characteristic of Neogene deep-water faunas, another may be related to P. paradoxum (Maxwell) from Duntroonian beds, and the third has no known close relatives.

Duplipecten parki (Marwick) was originally described as a Lentipecten, but it seems almost certainly to have evolved from D. waihaoensis (Suter), a common Waihao Downs (Bortonian) species. D. parki is also recorded from the Bortonian of Hampden (its type locality), Waihao Downs (upper part of section) and McCullough's Bridge.

The only other pecten recorded from the Tahu Member is a species of Chlamys perhaps related to C. williamsoni (Zittel) (Whaingaroan); Serripecten, represented by two species in the

Ngapuke Member, has not been recorded from the Tahu Member.

Limidae. Limea (Limea) is a member of a group of species ranging from Bortonian up to Opoitian (L. chathamensis Marwick) but only rarely collected because of the fragility of their shells. Mantellum inconspicuum Marwick from Lorne (Kaiatan) may be related.

The Limatula recorded from the Tahu Member is the earliest member of a well-defined endemic group which culminates in the Recent Limatula suteri (Dall). It seems to be distinct from L. trulla Marwick which occurs at a number of Kaiatan and Runangan localities near Oamaru.

Thyasiridae. The only member of this family recorded during the present study is a new species of Parathyasira from the Kapua Tuffs, the only fossil record of the genus known to the writer. Parathyasira occurs living in moderately deep waters in New Zealand and south-east Australia.

Erycinidae. This family is represented by a moderately common but infrequently collected form referred to Hemilepton (as a subgenus of Erycina), based on a European Lower Miocene species and hitherto not recorded from New Zealand.

Carditidae. The only carditid recorded from the Tahu Member is a fragmentary specimen representing a new species of Glyptoactis (Fasciculicardia) related to G. acanthodes (Suter), the common Waihao Downs (Bortonian) species.

Condylocardiidae. Condylocuna subaequilateralis (Maxwell) is moderately common in washings from the Tahu Member. It has a related species at Lorne (Kaiatan) and is probably ancestral to C. flemingi

Maxwell (Duntroonian-Altonian of North Otago and South Canterbury). C. subaequilateralis is the oldest known species of the genus.

Crassatellidae. Small, probably immature specimens of a crassatellid occurring in both the Tahu Member and Kapua Tuffs are referred somewhat tentatively to Eucrassatella (Eucrassatella) australis (Hutton), a species that is locally common in Bortonian (and probably late Dannevirke Series) shallow-water sediments in North Otago and South Canterbury. The small size of the shells from the former localities is attributed to deep-water conditions (see section on Paleoecology).

Cardiidae. The only representative of the family in the Tahu Member is the small Nemocardium (Pratulum) semitectum (Marwick), originally described from Lorne (Kaiatan) and recorded from several Kaiatan-Runangan localities in Oamaru district. The subgenus makes its first appearance in the Wangaloan /N. (Pratulum) modicum Marwick/ and occurs widely throughout the Cenozoic, in both neritic and bathyal faunas.

Veneridae. This family too, is poorly represented in the Tahu Member, only Marama (Hina) vaga Marwick (and probably Kuia aff. vellicata (Hutton)) having been found in this unit. The former species belongs to a well-defined group characteristic of deepish water faunas from at least Bortonian to Kapitean. The Kuia (represented by one juvenile valve) is closely related to a species that is widespread in Duntroonian-Altonian neritic beds in North Otago and South Canterbury. The genus ranges from Bortonian-Opoitian. The absence of Dosiniinae, common in Bortonian and younger shallow-water beds, is taken as further evidence for at least moderately deep

conditions for deposition of the Tahu Member.

Corbulidae. Two species of corbulids, Notocorbula allani n.sp. and Caryocorbula robini n.sp. are recorded from the Tahu Member. The former, also recorded from the Bortonian of McCullough's Bridge (Ngapuke Member) and Pahi, Northland, is closely related and probably ancestral to the widespread N. humerosa (Hutton) recorded from Duntroonian to Kapitean localities throughout the country. Caryocorbula robini, on the other hand, is very similar to the Altonian species C. pumila (Hutton).

Cuspidariidae. A single small valve of a Cuspidaria very similar to, if not conspecific with the Recent C. fairchildi Suter, is the only record of the family from the Tahu Member. The oldest known New Zealand Cuspidaria (? Dannevirke Series, Castle Hill Shaft) is described as having a shape "very close" to that of C. fairchildi (Finlay and Marwick 1937: 104), so this stock seems to have been unusually conservative.

Verticordiidae. The only verticordiid recorded from the Tahu Member is a damaged valve that resembles Verticordia (Spinosipella) ericia Hedley, originally described from deep water in south-east Australia but subsequently recorded from southern Africa and northern New Zealand (Crozier 1966: 45). The subgenus is also present in the Upper Eocene Glen Aire Clay of Victoria, Australia. No other fossil records are known to the writer.

The Tahu Member lacks the other species of verticordiids that give a distinctive character to the Bortonian molluscan fauna from Hampden.

2. SCAPHOPODA

A moderately rich scaphopod fauna (8 species) has been recorded from the Tahu Member and Kapua Tuffs. Unfortunately, comparison with other faunas is difficult, as scaphopods have in general received only cursory examination by New Zealand paleontologists. It is the writer's experience that the Cenozoic scaphopod fauna is far richer than commonly supposed and that the stratigraphic ranges of many species are quite restricted.

Dentaliidae. Of the four species of dentaliids recorded from the Tahu Member, three are quite common, while the fourth /Fustiaria (Fustiaria) beui n.sp./ is very rare. Dentalium (Fissidentalium) waihaoense n.sp. is similar and possibly ancestral to the late Cenozoic-Recent D. (Fissidentalium) zelandicum Sowerby, but the other species have no close relatives amongst described forms. Fustiaria (s.str.) has not previously been recorded from New Zealand; an undescribed species of Gadilina from the Kaiata Siltstone of Buller Gorge seems to be closer to the South Australian Upper Eocene F. (Gadilina) tatei (Sharp and Pilsbry) than to F. (Gadilina) maoria from the Tahu Member. The only other local records of the subgenus known to the writer are from deep-water siltstones of Clifdenian and Waiauan age in the Greymouth district. Dentalium (Fissidentalium) delli n.sp. is also recorded from the Kaiata Siltstone (Kaiatan) at Port Elizabeth, Westland.

D. (Fissidentalium) waihaoense is only doubtfully recorded from the Kapua Tuffs, but D. (Fissidentalium) delli and Fustiaria (Gadilina) maoria are both common.

Siphonodentaliidae. The three members of this family present

in the Tahu Member include a species of Cadulus (Gadila) that is very similar to C. (Gadila) zecaninus Laws from the Otaian of Pakaurangi, a species of the subgenus Polyschides which may be related to C. atavus Finlay & Marwick from the late Dannevirke Series of Kaitangata and the only New Zealand record of the tiny dentaliform genus Entalina.

Only one siphonodentaliid, Cadulus (Polyschides) kapuaensis n.sp., is recorded from the Kapua Tuffs.

3. GASTROPODA

Scissurellidae. A broken specimen of Anatoma from the Tahu Member marks the oldest record of the genus from New Zealand. A distinct species is present in the Kaiatan of Lorne, North Otago. Several Recent species are known from New Zealand, but the only other fossil record is A. miocenica (Laws 1939) from the Otaian of Pakaurangi Pt.

Trochidae. This family is poorly represented in the Tahu Member but includes the earliest record of Benthastelena, a distinctive calliostomatine genus based on a rare living species from New South Wales and recorded sporadically in the mid-Cenozoic of New Zealand. The only other trochid found in this unit, listed as (?) Conominolia n.sp. B, has no known close relatives.

Trochids are much more common in the Kapua Tuffs, probably because it offered a firmer substrate than the glauconitic sands of the Tahu Member. Zeminolia kapuaensis n.sp., the most abundant mollusc in the unit, is the oldest known member of the genus; strangely enough, it is more closely related to the Recent

Z. semireticulata (Suter) than to the compact group of mid-Cenozoic species Z. fossa Laws, Z. venusta Maxwell and Z. carinata Laws. Zetela also makes its first appearance in the Kapua Tuffs; Z. vulcania n.sp., also recorded from Lorne (Kaiatan), is closely related to Z. hutchinsoniana Laws from Pakaurangi (Otaian), and to a trochid from the Pliocene of Okinawa, but not to the Recent type species or to Z. awamoana Laws from the Altonian of North Otago. The Conominolia recorded from the Kapua Tuffs is similar to C. sulcatina (Suter) from the Deborah Tuffs (Whaingaroan) of North Otago. The genus ranges throughout the Cenozoic.

Skeneidae. The three species of skeneids recorded from the Tahu Member represent genera which are not uncommon in neritic post-Eocene sediments in New Zealand but rather rare in older beds. Lissotesta and Submargarita make their first appearance in the Tahu Member, but Brookula is also known from Bortonian shellbeds in the upper Waihao valley.

Rissoidae. The only rissoid recorded from the Tahu Member, Lironoba (Nobolira) eocenica n.sp., is the earliest known species of the subgenus (and genus) and is closely related to L. (Nobolira) polyvincta Finlay from the Altonian of North Otago. A distinct species is not uncommon in the Waiareka Tuffs at Lorne (Kaiatan). The family is first known from the Mangaorapan of White's Creek, North Canterbury, but Eocene records are very sporadic, probably because suitable lithofacies are lacking.

Cerithiopsidae. This family is well represented in the Tahu Member, but no species have been recorded from the Kapua Tuffs. Cerithiella (Eumiopila) aoteana n.sp., one of the largest New Zealand

cerithiopsids, is the type species of a new subgenus that differs from Cerithiella (s.str.) in protoconch features. There are no other records of the genus in New Zealand, but C. cribraoides (Tenison-Woods) from the Balcombian of Victoria, Australia, is remarkably similar in teleoconch features to the McCullough's Bridge species. Waiakakhia n.gen., proposed for a Tahu Member species, is not definitely known elsewhere, but the Hampden species Cerithiella tricincta Marshall may prove to belong here. Spinoseila bicincta n.gen., n.sp. has a close relative in a Kaiatan fauna from Inangahua but the genus is otherwise not recorded away from McCullough's Bridge. "Paramendax" disparilis n.sp. is the oldest known species of a group that survives today in bathyal depths off Otago Peninsula and which may be represented by a number of fossil species. Notoseila (s.str.) makes its first appearance in the Tahu Member, but the other two species of Notoseila, N. gagei n.sp. and N. attenuissima (Marshall & Murdoch), represent a new subgenus, Eoseila, otherwise known only from Hampden (Bortonian) (type locality of N. attenuissima).

Turritellidae. Two species of turritellids, Spirocolpus waihaoensis (Marwick) and Zeacolpus lornensis (Marwick) are recorded from the Tahu Member and Kapua Tuffs. S. waihaoensis is the type species of a distinctive genus with a stratigraphic range of Wangaloan to Waitakian (Marwick 1971: 10) (i.e. throughout the Paleogene), also recorded from the Upper Eocene of South Australia /S. aldingae (Tate) - Garrard 1972: 326/. S. tophinus (Marwick) described from Lorne (Kaiatan) is closely related to S. waihaoensis. Zeacolpus lornensis (originally described from Lorne) is possibly the earliest member of Marwick's "fyfei" stock which ranges up to Waiauan (see taxonomic section).

Pareoridae. Pareora sublaevis Maxwell, described from the Waiareka Tuffs at Lorne (Kaiatan), is common in washings from the Tahu Member. The genus has a known range of Mangaorapan to Opoitian in New Zealand and is also recorded from the Upper Eocene of South Australia (Mesalia stylacris Tate). The Mangaorapan species (from White's Creek, North Canterbury) is very similar to P. sublaevis and may be directly ancestral.

Strombiformidae. New Zealand members of this taxonomically difficult group have not received much attention from paleontologists, so the affinities of the McCullough's Bridge are only imperfectly known. All four species recorded from the Tahu Member, however, appear to have close relatives in younger faunas. Strombiformis waihaoensis (Allan) is very similar in size and other features to S. otaioensis (Laws) (Otaian, Bluecliffs) and also to S. danae (Tenison-Woods) from the Balcombian of Muddy Creek, Victoria, while S. sutcliffei and S. arnoensis n.spp. are related to Balcis lento-contracta Laws and B. kaiparaensis Laws respectively, both of the last-named species being from Otaian or Altonian beds at Pakaurangi. Niso neozelanica Suter was originally described from the Duntroonian of Wharekuri, Waitaki River, but apart from their greater size, the two specimens recorded from the Tahu Member seem indistinguishable from the holotype.

Apporhaidae. The presence of Dicroloma (s.l.) zelandica Marshall in the Tahu Member and Kapua Tuffs is noteworthy because of the general rarity of Apporhaidae in the New Zealand Cenozoic and because the genus is elsewhere unknown from post-Maastrichtian beds. Further comments on this relict group are given in the systematic section. D. zelandica was described from Hampden.

Calyptraeidae. The warm-water genus Cheilea which ranges from Bortonian to Waipipian (Beu 1973: 322) in New Zealand is represented by the unusual species C. janitrix Maxwell. Sigapatella, which first appears in the Bortonian and is generally widespread in the rest of the Cenozoic, has not been recorded, possibly because of an unsuitable substrate.

Trichotropidae. This family is represented in the Tahu Member by the rather uncommon species Miplioderma (Eosirius) admeteforme (Maxwell) which differs from species of Miplioderma (s.str.) chiefly in protoconch features. Miplioderma (s.str.) has a recorded range of Duntroonian to Mangapanian in New Zealand but Eosirius is not known away from McCullough's Bridge.

Four species of triviids, all of them rare or uncommon, have been recorded from the Tahu Member. A small species of Ellatrivia, possibly conspecific with E. pinguior (Marwick) from Lorne, is the oldest representative of the subfamily from New Zealand. Of the eratoines, Lachryma cf. vulcania (Marwick) is similar to another Lorne species and is the earliest known member of a genus which ranges up to the Waiauan in New Zealand and still survives in south-east Australian waters. Proterato (Archierato) accola Laws is close to the Hampden species P. (Archierato) antiqua (Marshall), while P. (?Archierato) sepositum (Laws) is an unusual form that is possibly ancestral to a small group of Duntroonian-Clifdenian species.

Naticidae. Naticids are well represented in the Tahu Member in terms of both diversity and abundance. Tanea praeconsors (Finlay), also recorded from the Bortonian of Waihao River, is the earliest known species of a genus that ranges throughout the New Zealand Cenozoic up to the present day. Taniella notocenica intermedia n. subsp. is

intermediate between the Hampden species T. bacca (Marwick) and the widespread, long-ranging T. notocenica notocenica (Finlay). It is also recorded from Lorne and Trig M, Totara (Runangan). Magnatica (Spelaenacca) parilis Finlay, also recorded from the Ngapuke Member (Bortonian) and possibly also present at Lorne and Trig M, is closely related to the Duntroonian species M. (Spelaenacca) sutherlandi (Marwick). The subgenus has a known range of Wangaloan to Altonian. Carinacca waihaoensis (Suter), the most distinctive of the naticids from the Tahu Member, is not known away from McCullough's Bridge. C. allani (Marwick), represented by a single specimen from the Tahu Member, is otherwise recorded only from Bortonian localities in North Otago and South Canterbury. The genus is known only from the Bortonian and Kaiatan of New Zealand.

Polinices (Polinella) esdailei(Marwick), originally described from Lorne and also recorded from Trig M, has a close relative in the Bortonian of Waihao Downs. The subgenus, which seems to be endemic, is recorded throughout the Cenozoic from Wangaloan to Waipipian. Neverita pontis (Marwick), also tentatively recorded from Waihao Downs, is the only known New Zealand representative of this warm-water genus. Friginatica (Sulconacca) suturalis (Hutton), one of the most common molluscs in the Tahu Member, belongs to a rather conservative group of species that first appears in the Bortonian and ranges up to the Waipipian. Tahunacca haasti (Marwick), by contrast, is the only known species of a new genus related to Sulconacca. It is also recorded from the Bortonian of Hampden and Kaiatan of Port Elizabeth. Globisinum elegans (Suter), present also at Waihao Downs, appears to represent a short-lived, weakly sculptured offshoot from the main lineage that stretches from the Wangaloan G. spirale (Marshall) to the Recent G. drewi (Murdoch).

The four naticid species recorded from the Kapua Tuffs are conspecific with forms from the Tahu Member.

Cymatiidae (based partly on information supplied by Dr A.G. Beu). Cymatiids are rare in the Tahu Member, but four, possibly five, species have been recorded from it. The most common one, Austrosassia cyphoides (Finlay) was described from Lorne and is also recorded from Bridge Point, Kakanui (Runangan); it may be ancestral to the Recent New Zealand and south-eastern Australian species A. parkinsoniana (Perry). A second species of Austrosassia, represented by a single specimen, is a member of a distinct lineage that includes the Whaingaroan species A. procera Finlay. Austrosassia is first known from the Bortonian and is largely endemic to New Zealand and southern Australia. Sassia n.sp., by contrast, belongs to a dominantly Northern Hemisphere genus, although a living species is present in south-east Australian waters. Closely related species, possibly conspecific, occur in the Bortonian at Hampden and Waihao Downs and the Kaiatan of Port Elizabeth. Sassia has a very sporadic distribution in New Zealand, the only other records being of a distinct species /S. decagonia (Finlay)/ from Waihao Downs and another from the Mangaorapan of White's Creek, North Canterbury. Northern affinitives are also suggested by Distorsio (Personella) beui Maxwell, so far known only by the holotype; further details are given by Maxwell (1968). The Tahu Member is probably also the type horizon of Haurokoa marwicki (Finlay); no additional specimens have been collected from McCullough's bridge but it is rather common in the Waiareka Tuffs at Lorne. This is the earliest local record of Haurokoa (known only from the Cenozoic of New Zealand and southern Australia) but species attributed to it are recorded from the lower Eocene of Australia.

Cassidae. An apical fragment of a Galeodea, possibly referrable to the Hampden species G. geniculosa Marwick, is the only cassid recorded from the Tahu Member. The genus ranges from ?Dannevirke Series (Castle Hill Shaft) to Recent in New Zealand.

Ficidae. Small, probably juvenile specimens of Ficus sp. from the Tahu Member and Kapua Tuffs are the earliest record of this warm-water genus from New Zealand.

Architectonicidae. Wangaloa ngaparaensis (Suter) is moderately common in both the Tahu Member and the Kapua Tuffs. The genus, which appears to be endemic to New Zealand and south-east Australia, occurs sporadically throughout the Cenozoic, from Wangaloan to at least Waipipian or even Mangapanian (Awatere River). The only other architectonicid recorded from the Tahu Member is Pseudomalaxis asculpturatus Maxwell, the only species of this Northern Hemisphere genus so far described from New Zealand. A related form, possibly conspecific, is present in the Wharekuri Greensands (Duntroonian), and another very similar species has recently been found in the Upper Eocene of South Australia.

Mathildidae. The most common mathildid in the Tahu Member, Mathildona allani Maxwell, has no known congeners in the New Zealand Cenozoic and even its relationship to Mathildona euglypta Iredale (Recent, N.S.W.), the type species, is rather uncertain. Mathilda (Opimilda) pontis (Maxwell), however, is similar to the Recent M. (Opimilda) decorata aupouria (Dell) from northernmost New Zealand. The Gegania recorded from the Tahu Member is considered to be conspecific with the long-ranging species G. olsoni (Maxwell), originally described from the Waitakian of Hakataramea Valley but recorded from

localities in North Otago and South Canterbury ranging in age from Bortonian to Otaian.

Triphoridae. The only member of this family recorded from the Tahu Member is Notosinister(?) aoteaensis (Marshall & Murdoch), originally described from Hampden. Generic affinities of this species are uncertain.

Epitoniidae. This family is moderately well represented in the Tahu Member with 7 species, all described as new, recorded in the present study. Cirsotrema waihaoense belongs to a group of species that includes the common mid-Cenozoic C. lyrata (Zittel) rather than to the group that includes the Hampden species C. kuriense Marwick. Opalia marshalli appears to be related to a Hampden shell described as Epitonium tenuispiralis Marshall, but otherwise has no recorded congeners in the New Zealand Cenozoic. Pliciscala flemingi is not particularly close to P. komitica Laws, the only other New Zealand species so far described. The type species is a Paris Basin Eocene shell. Turriscala allani has no close local relatives and its generic placement is somewhat uncertain. Hemiacirsa lawsi is the oldest known New Zealand species of a group that includes species from Wharekuri (Duntroonian), Bluecliffs (Otaian), Pakaurangi (Altonian), Parengarenga Harbour (Otaian and Altonian) and (according to Laws 1944: 308) Clifden (probably Altonian or Clifdenian). Notacirsa vetusta is the oldest representative of an endemic genus with several mid-Cenozoic species. Tahuscala perparvula is the type species of a new genus otherwise known only from a shellbed of Bortonian (or older) age in the upper Waihao valley.

Muricidae. Muricids are uncommon in the Tahu Member and the few species recorded belong to genera which are well represented in younger beds. These include the earliest local record of Pterynotus s.str.; the species is identified as P. laetificus Finlay, originally described from the Waiauan of Clifden but subsequently recorded from beds ranging in age from Waitakian to Kapitean (Beu 1970b). Pterochelus tahuensis Maxwell differs from other described New Zealand species in protoconch features but appears to be related to an undescribed species from the Bortonian of the Upper Waihao valley (Maxwell 1971: 759). Two species of Poirieria are recorded from the Tahu Member. One is close to, if not conspecific with, the widely distributed, long-ranging P. primigena Finlay, ancestral to the living P. zelandica (Quoy & Gaimard); the other, P. denticulifera Maxwell, has some features in common with a North American Lower Eocene species and may be related to the other living New Zealand species P. kopua Dell (Maxwell 1971: 762-7). Xymene apipagodus Ponder is the oldest New Zealand trophonine.

Columbariidae. The only representative of this family found in the Tahu Member is Coluzea climacota (Suter) which may be ancestral to the well-known mid-Cenozoic species C. dentata (Hutton). The genus makes its first appearance in New Zealand in the Bortonian (C. aff. climacota from Hampden) and ranges widely throughout the Cenozoic from Duntroonian onwards.

Columbellidae. Liratilia pulchella n.sp. which is recorded from both the Tahu Member and the Kapua Tuffs, is the oldest known record of an endemic genus with a poor fossil record. The only other columbellid recorded from McCullough's Bridge (probably from the Tahu Member), is Mitrella (Bastropia) mackayi (Suter). The

holotype is from an uncertain locality, possibly Waihao Downs (Bortonian) where the species has also been recorded. M. (Bastropia) mackayi is remarkably similar to the type species of the subgenus from the Middle Eocene of Texas; there are no other New Zealand records of Bastropia known to the writer.

Neptuniidae. Two species of Austrofusus (s.str.), one of the most characteristic New Zealand Cenozoic genera, have been recorded from the Tahu Member. A. separabilis n.sp., also recorded tentatively from Hampden, is related to A. acuticostatus (Suter) from Waihao Downs (Bortonian) and may be ancestral to such mid-Cenozoic species as A. precursor Finlay (Duntroonian, Chatton) and A. spiniferus (Finlay & McDowell) (Altonian, North Otago). The other species, which is more common in the Kapua Tuffs than in the Tahu Member, is referred to A. bicarinatus (Suter), a poorly known species described from the Whaingaroan of Coleridge Creek, Castle Hill Basin. Related species occur in the Pareora Series of Awakino district and the Altonian of Mokihinui R, S.W. Nelson. The remaining neptunid recorded from the Tahu Member, Nassicola sp., belongs to a widespread, conservative endemic genus that ranges throughout the Cenozoic, from Wangaloan to Waipipian (Beu 1973: 324-7).

Colubrariidae. Colubraria neozelanica Maxwell, which occurs rarely in the Tahu Member, is closely related to C. sutherlandi Beu, recorded from a number of localities of Waitakian-Otaian age in North Otago and South Canterbury (Beu 1973: 328). The shell figured by Maxwell (1966: fig. 22) as C. cf. neozelanica (probably from Lorne) represents another, related species.

Fasciolariidae. This family is moderately well represented

in the Tahu Member. Lathyrulus fraudator n.sp., one of the most common molluscs in the unit, has no known relatives in the New Zealand Cenozoic and its generic affinities are uncertain. Fractolatirus optatus (Marshall & Murdoch) is also without known New Zealand congeners but is considered to be related to the type species of Fractolatirus from Sydney Harbour. The highly variable Exilia (Zexilia) waihaoensis Suter has a close relative in E. (Zexilia) hampdenensis (Marwick) from Hampden; the subgenus is typical of deepish-water faunas from at least Bortonian to Waiauan in New Zealand and is probably derived from a North American species of Exilia. The endemic fusinoid genus Falsicolus is represented by F. solida (Suter), the type species of a new subgenus that has a recorded range of at least Bortonian to Kapitean; Falsicolus s.str., present in the Bortonian of North Otago and the late Kaiatan of Lorne, has not been recorded from the Tahu Member. F. solida is closely similar to F. alta (Marshall) from Hampden. Fusinus waihaoicus Laws, which was described from McCullough's Bridge, may also be from the Tahu Member; its generic affinities are uncertain, but a similar, undescribed species is present at Pakaurangi Pt (Otaian). If correctly assigned to Fusinus, F. waihaoicus and the Otaian species represent the only New Zealand Cenozoic records of the genus, although two living species have been recorded from the northern part of the North Island in recent years (Powell 1967, Ponder 1968c).

Mitridae. Although mitriform gastropods are quite common in the Tahu Member, the only true mitrid so far recorded is Cancilla (Fusimitra) hectori (Hutton) (also present in the Kapua Tuffs). This species was first described from a probable Bortonian locality in the Waihao River and has been collected from Pareora River (Bortonian) and

Lorne as well as McCullough's Bridge. Reference to Fusimitra suggests North American Eocene affinities, but it is also possible that F. hectori is a small, early species of the endemic taxon Clifdenia, otherwise recorded from Duntroonian to Lillburnian.

Volutomitridae. Two species of volutomitrids, Waimatea inconspicua (Hutton) and Conomitra plicatella (Marshall & Murdoch) are amongst the most common molluscs in the Tahu Member. The former species is also present in the Kapua Tuffs and at Lorne and a related though distinct species, W. amplexa Finlay, occurs at Waihao Downs (Bortonian). The genus ranges from Bortonian to Recent in New Zealand and from at least Upper Eocene to Recent in south-eastern Australia. The highly variable Conomitra plicatella belongs to a genus that is widespread in Paleogene deposits in Europe and North America and is also recorded from the Middle Miocene of Victoria, Australia (Cernohorsky 1970: 105-114). The genus is also present in a Bortonian shellbed in the Upper Waihao Valley. Proximitra parki (Allan), also present in the Kapua Tuffs, is the earliest known species of a genus that was common in the mid-Cenozoic in North Otago and South Canterbury and has also been recorded from beds of similar age in south-eastern Australia, Lower Miocene of Florida, and Eocene of France (Cernohorsky 1970: 132-6).

Marginellidae. Three species of marginellids have been recorded from the Tahu Member. One of these, Volvarinella aveniformis (Marshall), was originally described from Hampden; the other two, Protoginella (Protoginella) cenodoxa n.sp. and P.(? Alaginella) ponderi n.sp., have not been found elsewhere but seem to be related to species from mid-Cenozoic beds in the North Otago-South Canterbury area.

Volutidae. Only one species of volute, Waihaoia (Waihaoia) allani Marwick, was recorded from the Tahu Member and Kapua Tuffs during the present study. This belongs to a group that is unknown in post-Duntroonian beds in North Otago and South Canterbury but was common from at least Altonian to Lillburnian in Southland, possibly because of the warmer conditions that seem to have prevailed there at that time. In the taxonomic section it is suggested that Waihaoia is ancestral to the taxon Spinomelon which first appears in the Duntroonian and ranges throughout most of the Neogene.

The general rarity of volutes in the Upper Eocene of New Zealand contrasts with their relative abundance and diversity in the Bortonian. At such localities as Waihao Downs and Kakahu in South Canterbury occur species of Waihaoia, Mauira and Notoplejona (= Athleta according to Darragh 1971: 166). The last-named taxon is not known from post-Bortonian faunas, but Mauira re-appears in the Altonian of North Canterbury and occurs sporadically throughout the Miocene. The local extinction of Athleta (which persists into the Miocene in Europe) and the prolonged disappearance of Mauira after the Bortonian may be the result of cooling in late Bortonian-early Kaiatan times as suggested in the Paleoecology section.

Olividae. Two species of ancilline olivids, Ancillus olsoni n.sp. and Amalda (Gracilispira) morgani (Allan) are common in the Tahu Member. The former species (also present in the Kapua Tuffs) has a close relative in the Kaiatan of Inangahua district but otherwise stands apart from all other New Zealand ancillines. The type species of Ancillus, A. buccinoides (Lamarck) from the Middle Eocene of Paris Basin, differs significantly from A. olsoni and is in fact closer to a species from Hampden. The affinities of A. olsoni seem

to be with a deep-water Recent species from Indonesia. Amalda (Gracilispira) morgani is by contrast a member of a rather conservative group of species ranging from at least late Dannevirke Series to Recent; it is also recorded from several Bortonian localities in North Otago and South Canterbury but has not so far been found in the Kapua Tuffs where its place is apparently taken by A. (Alocospira) komata n.sp. This is the earliest known species of a subgenus which is widespread in the Cenozoic of both New Zealand and south-eastern Australia. Amalda (Micrancilla) granum n.sp., the rarest of the ancillines from the Tahu Member, is the type species of a new subgenus that is otherwise known only from the Kaiatan of Inangahua district, Otaian of Pareora River, and Altonian of Clifden.

Conidae. Two species of cones, both of them rare, have been recorded from the Tahu Member. Conus (s.l.) gagei n.sp., so far known only by the holotype, appears to be related to C. pseudoarmorious Marshall & Murdoch from Hampden, and C. thorae (Finlay) from Pakaurangi (Otaian or Altonian). Conilithes tahuensis (Allan), also doubtfully recorded from the Tahu Member, belongs to the most widespread of the genera of cones known from the New Zealand Cenozoic, with a stratigraphic range of Bortonian to Waiauan.

Turridae. This large family is well represented at McCullough's Bridge, with 20 species recorded from the Tahu Member alone in the present study. Such diversity is at least partly attributable to the depth of deposition inferred for this unit (outer shelf), but the warm conditions that are thought to have prevailed at this time may have been another contributing factor.

The subfamily Clavinae, so characteristic of Neogene deepish water faunas in New Zealand, is represented by the rather uncommon

Tahudrillia simplex Powell. The genus is monotypic and known only from the Tahu Member at McCullough's Bridge.

Four species of turrines, Gemmula waihaoensis Finlay, G. duplex (Suter), G. bimarginata (Suter) and Eoturris complicata (Suter) have been recorded from the Tahu Member. The first of these is also present in the Kapua Tuffs, while G. duplex and E. complicata are also recorded from Hampden. The other species of Gemmula recorded from the Bortonian of Hampden, viz. G. margaritata (Marshall), G. reticulata (Marshall) and G. polita (Marshall) do not appear to be closely related to the McCullough's Bridge species. Gemmula, which is first known from the Bortonian in New Zealand, has not been recorded from post-Waitakian beds in North Otago-South Canterbury, but elsewhere in the country it ranges as high as Opoitian. Eoturris is an endemic genus that appears to be restricted to the Paleogene; its recorded stratigraphic range is late Dannevirke Series (Matau fauna of Kaitangata district) to Waitakian.

The Turriculinae is the best-represented of the turrid subfamilies at McCullough's Bridge; nine species are recorded from the Tahu Member and three from the Kapua Tuffs in this study. Marshallena neozelanica (Suter), also recorded from Hampden, is not uncommon in the Tahu Member; it is the type species of a genus that is known only from the Bortonian and Kaiatan in New Zealand but survives in deep waters in the Indo-Pacific region (see Taxonomic section for revision of Marshallena and Marshallaria). Two species of Marshallaria s.str. are present in the Tahu Member, M. spiralis (Allan) (type species of the genus) and M. decipiens n.sp.; the latter is also recorded from the Kapua Tuffs. M. spiralis, doubtfully recorded from Waihao Downs, is closely similar to M. multicincta (Marshall) (Wangaloan, Wangaloa

and Boulder Hill) and M. senilis (Marshall & Murdoch) (Bortonian, Hampden); M. decipiens, however, belongs to a different stock, one that includes M. serotina (Suter) (Bortonian, Waihao Downs), and most of the younger species of Marshallaria s.str. Also present in the Tahu Member is Marshallaria (Zeatoma) allani n.sp., the earliest member of a distinctive new subgenus that ranges up to the Waipipian, and a fourth species, listed as Marshallaria (s.l.) n.sp. C, without obvious affinities to any other described form. Tahuia formosa (Allan), a species that is superficially similar to the more common Marshallaria decipiens, is the type species of a new genus that includes T. esdailei (Marwick) from Lorne (Kaiatan) and an undescribed species from the Otaian of Pareora River. Notogenota finlayi Powell belongs to an endemic genus that is so far known only from the Bortonian and Kaiatan; it is closely related to the type species N. goniodes (Suter) from Waihao Downs. Zemacies marginalis (Marshall), originally described from Hampden, is a member of a genus that ranges virtually throughout the Cenozoic (Wangaloan to Waipipian) in New Zealand and is also known from the Oligocene of Victoria, Australia (Powell 1944: 21). The remaining turriculine recorded from the Tahu Member is the ornate Cochlespira (Tahusyrinx) maorum (Marshall & Murdoch), type species of the subgenus and differing from the deep-water Indo-Pacific and Caribbean Cochlespira s.str. only in minor protoconch details. The only other New Zealand record of Tahusyrinx is from a Bortonian shell-bed in the upper Waihao valley, but the subgenus seems to have been present in the Eocene in France (see taxonomic section). Cochlespira s.str. is known from the Altonian of Parengarenga Harbour and the Waiauan of Greymouth district.

The three species of Turriculinae recorded from the Kapua Tuffs are Marshallaria decipiens n.sp., Parasyrinx (Lirasyrinx) powelli n.sp.

and Cosmasyrinx (Tholosyrinx) n.sp. The only other records of the subgenus Lirasyrinx are from the Kaiatan of Inangahua district, Duntroonian of Wharekuri (type locality of the type species) and Waitakian of Otiake. Parasyrinx s.str., which is probably derived from Lirasyrinx, has a stratigraphic range of Duntroonian to Altonian. The new subgenus Tholosyrinx is based on a Kaiatan species from Port Elizabeth near Greymouth; the only other record is the undescribed species from the Kapua Tuffs. Cosmasyrinx s.str. is known only from deep-water Miocene siltstones from Westland, Gisborne district and Wairarapa.

The Zonulispirinae is represented doubtfully by (?) Inquisitor waihaoensis Powell which occurs uncommonly in the Tahu Member and possibly in the Kapua Tuffs. As pointed out in the taxonomic section, it seems to be only superficially similar to the Lower Miocene I. awamoensis (Harris).

Two species of Borsoniinae have been collected from the Tahu Member. Borsonia crassiaxialis n.sp. is not closely related to any of the other described New Zealand species, which range in age from Bortonian to at least Waiauan. Eoscobinella tahuia Powell is the type species of a distinctive genus otherwise definitely known only from The Cliffs, Nelson (probably Duntroonian) and Parengarenga Harbour (Altonian). /The shell described by Beu (1970c: 235) as Eoscobinella secunda n.sp. from the Tongaporutuan of Wairarapa is not considered to be congeneric with E. tahuia/.

The Mitrolumninae is represented in the Tahu Member by two species of Cordieria. One of these, the highly variable C. rudis (Hutton), is one of the most abundant molluscs in both the Tahu Member and the Kapua Tuffs. It closely resembles some of the European Eocene

species. Cordieria huttoni Finlay, however, is a distinctive species that may not even be congeneric with C. rudis. The only other record of the genus in New Zealand is from the Kaiatan of Inangahua district.

The only daphnelline recorded from the Tahu Member is the species described herein as "Syngenochilus" anceps n.sp. This differs in protoconch details from typical Syngenochilus (so far known only from the Cenozoic of south-eastern Australia) but closely resembles an undescribed species from the Upper Eocene Glen Aire Clay of Victoria. A related species is present in the Waitakian of Hakataramea Valley.

Terebridae and (?) Pervicaciidae. Terebroids are rather uncommon at McCullough's Bridge. Zeacuminia tahuia Finlay, recorded from Hampden (type locality) and from both the Tahu Member and Kapua Tuffs, is the type species of the most widespread of the terebroid genera recorded from New Zealand, with a stratigraphic range of Bortonian to Waipipian. The other terebroid recorded from the Tahu Member is tentatively referred to Pervicacia, a genus otherwise known from Waitakian to Recent in New Zealand and from the Cenozoic and Recent of south-eastern Australia.

Cancellariidae. None of the eight species of cancellariids recorded from the Tahu Member can be regarded as common, half of them in fact being represented by only one or two specimens apiece. Narona (Naronista) kaitara n.sp. is the type species of a distinctive new subgenus so far known only from McCullough's Bridge. Narona itself (tropical Eastern Pacific in distribution today) has a poor fossil record but is known from the Neogene of the Caribbean. Unitas marshalli (Allan), only doubtfully congeneric with the Paris Basin

Eocene type species, has a close relative in an undescribed form from Sisters Ck, Hakataramea Valley (Waitakian). Fusiaphera(?) jenkinsi n.sp. shows no close similarity to any other cancellariid so far recorded from New Zealand and is only doubtfully referred to Fusiaphera. Plesiocerithium (s.l.) palmerae n.sp. is similar in general teleoconch features to species of Plesiocerithium and Cancelrana from the Eocene of Europe and North America, but differs in protoconch details and so may be subgenerically distinct. No similar forms are known from elsewhere in the New Zealand Cenozoic. Parapepta pinguis n.sp. is the type species of a new genus allied to Inglisella, so far known only from McCullough's Bridge. Inglisella itself (apparently closely related to Sveltella from the European Eocene) makes its first appearance in the Tahu Member, ranges up to the Opoitian in New Zealand and is the most diverse of all New Zealand cancellariid genera. Anapepta s.str., a distinctive taxon that appears to be endemic to New Zealand, is represented by two species, A. lamellifera n.sp., related to the type species A. anomala (Marshall & Murdoch) from Hampden, and A. allani n.sp., which is similar to A. finlayi Marwick from the Altonian of Awamoa Ck. Anapepta s.str. has a known range of Bortonian to Waiauan.

Pyramidellidae. This family is well represented in the Tahu Member but none of the ten species recorded is particularly common. The three species of Turbonilla found in this unit are not very close to any other described forms although T. tahuensis Laws is superficially similar to some Neogene species of the genus Mormulasta. In New Zealand, Turbonilla ranges from at least Bortonian to Recent. Pyrgiscilla, a genus at present living in New Zealand and Australia, is represented by a species tentatively referred to P. hampdenensis

(Finlay), originally described from Hampden. Of the two species of Syrnola recorded from the Tahu Member, S. koekoa n.sp. is a highly distinctive species that resembles species of Terelimella, a genus supposedly related to Eulimella and ranging from Duntroonian to Recent, while S. arnoensis n.sp. is similar to S. aclyformis Marwick from Chatton (Duntroonian). Puposyrnola lawsi n.sp. is the oldest neozelanic (and apparently, oldest Pacific) record of a genus that elsewhere ranges from Paleocene to Recent (Corgan 1972: 359). The genus also occurs in the Clifdenian and in the New Zealand Recent fauna. Two species of Odostomia are present in the Tahu Member: O. waihaoensis n.sp., a large form that is related to such species as O. waipaoa (Marwick) from Muddy Ck (Clifdenian), O. bartrumi Laws (Opoitian, Kaawa Ck), O. zecorpulenta Laws (Nukumaruan, Hawkes Bay) and O. corpulentoides Dell (Recent) and O. iota n.sp. that seems to be closest to O. gorensis Laws (Duntroonian, Chatton).

Sinuatodostomia aperta n.sp. is the second New Zealand species of this rare genus (based on a Recent Japanese species) to be described; the only other local records known to the writer are from a Bortonian shellbed in the Upper Waihao valley and in the Rifle Butts Siltstone (Altonian) of Oamaru district. The remaining pyramidellid known from McCullough's Bridge, probably from the Tahu Member, is Elodiamea eocenica Laws, the only New Zealand record of this typically warm-water genus.

Acteonidae. Two species of acteonids have been recorded from the Tahu Member. One of these, Maxacteon rudmani n.sp., is similar to the Recent species M. milleri Rudman and is considered to be congeneric, although confident discrimination of Maxacteon from Acteon depends on anatomical features. Acteon-like shells occur throughout

the New Zealand Cenozoic. The other acteonid, Triploca waihaoensis Marshall & Murdoch, closely resembles the type species from the Upper Eocene of South Australia; the only other New Zealand record of the genus is from the Bortonian of the upper Waihao valley.

The acteonid recorded from the Kapua Tuffs as (?)Acteon n.sp. is an unusually slender species that may prove referrable to the genus Tenuiacteon which is based on a North American Eocene species.

Ringiculidae. The smaller of the two species of ringiculids recorded from the Tahu Member, Ringiculina tenuilabrum n.sp., is very similar to, if not conspecific with, a species from the Kaiatan of Inangahua district. The genus ranges from Bortonian to Recent in New Zealand and seems to be more typical of deepish-water faunas than the allied Ringiculella. Superstes marshalli Finlay & Marwick, originally described from Hampden (Bortonian), is rather rare in the Tahu Member but is one of the most common molluscs in the Kapua Tuffs. It is closely similar to, but probably distinct from, S. phoenix Finlay & Marwick from the Waiareka Tuffs at Lorne. Superstes is an endemic genus related to Gilbertina from the Paleocene-Miocene of Europe and North America and having a known range from Dannevirke Series (Matau fauna of Kaitangata district) to at least Kaiatan and possibly as high as Waitakian or Otaian (specimen from "Grey Marls", Weka Pass - see Finlay and Marwick 1937: 110).

Philinidae. The holotype of Philine zeprisca n.sp. is the only philinid recorded from the Tahu Member during the present study. P. zeprisca is the oldest species recorded from New Zealand and does not appear to be closely related to the other New Zealand species so far described (see Rudman 1970).

Scaphandridae. The only representative of this family in the Tahu Member is Cylichnania semiteres n.sp., a member of a distinctive endemic genus that ranges throughout most of the Cenozoic (Wangaloan to Waipipian). A second species (Cylichnania n.sp. B) is present in the Kapua Tuffs, which has also yielded a scaphandrid with some of the features of the genus Kaitoa but herein classed as Scaphander(?) n.sp. Scaphander first appears in the Kaiatan at Lorne and ranges throughout the Cenozoic to the present day in New Zealand.

Spiratellidae. Spiratellids have not been recorded from the Tahu Member but are moderately common in the more fossiliferous lenses in the Kapua Tuffs. Spiratella kapuaensis n.sp. is superficially similar to S. limata Marwick from the approximately coeval Waiareka Tuffs at Lorne but differs from it and other New Zealand species in having weak spiral sculpture. The other species, listed as Spiratella n.sp. B, is conspecific with a form that is common at Lorne and Bridge Pt, Kakanui (Runangan).

Cavoliniidae. Damaged specimens of a moderately large Clio, probably the same species that occurs at Lorne, are the only Cavoliniidae recorded from the Tahu Member. Rare specimens of Hyalocylis from the Kapua Tuffs belong to a species recorded from various Bortonian to Runangan localities in North Otago and are possibly the same as Clio annulata Tate, described from the Upper Eocene of South Australia.

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4. SUMMARY

In summary, the 164 genus-group taxa present in the Tahu Member at McCullough's Bridge and in the Kapua Tuffs may be placed in the following categories (see also Table 4):

(1) Taxa which make their first appearance in the Dannevirke Series in New Zealand and range up into at least the Wanganui Series, and in most cases, up to the present day. Most (15) of the 24 taxa included here appear in the Wangaloan (i.e. about Teurian, correlated with the Paleocene), but some are first known from younger faunas that have not yet been correlated with the stages of the Dannevirke Series based on foraminiferal criteria. Examples are faunas from Castle Hill Shaft, Kaitangata (described by Finlay and Marwick 1937) and Otaio Gorge (Marwick 1960). These could be as young as Porangan (i.e. only slightly younger than Bortonian) and it may be argued that taxa making their first appearances therein could equally well be included in category 2. The distinction between categories 1 and 2 is rather arbitrary, especially as it is very likely that many of the taxa in 2 will eventually be identified in pre-Bortonian faunas. Nevertheless, the Bortonian does appear to be characterised by a marked influx of important genus-group taxa, not only in the Mollusca but also in the better-documented Foraminiferida (see Hornibrook 1953: 438), so the distinction is useful and maintained despite the above qualifications. Taxa included in this category are:

Ennucula	*Polinices (Polinella)
Saccella	*Globisinum
Jupiteria	Galeodea
Chlamys (s.l.)	*Wangaloa
Eucrassatella	*Nassicola

Nemocardium (Pratulum)	*Amalda (Gracilispira)
Caryocorbula	*Zemacies
Cuspidaria	Odostomia
*Conominolia	Acteon
*Zeacolpus (s.l.)	*Cyclichnania
*Pareora	Spiratella
Strombiformis (s.l.)	*Taniella

Eleven of these taxa (marked by an asterisk in this and subsequent lists) are either endemic to New Zealand or to New Zealand and to south-east Australia; the remainder are cosmopolitan forms.

(2) Taxa which are first known from the Bortonian or Kaiatan in New Zealand but, like the taxa in category 1, range up into the Wanganui Series or the present day. As noted above, some may eventually be found in pre-Bortonian faunas.

The following 66 taxa are included here:

*Austrotindaria	Anatoma
*Ledaspina	*Zeminolia
Ledella	Zetela
Yoldiella	*Lissotesta
Sarepta	Submargarita
Bathyarca	*Brookula (Aequispirella)
Limopsis	*Lironoba (Nobolira)
Lissarca	*n.gen. aff. Paramendax
Amygdalum	Notoseila
Parvamussium	Cheilea
Limea	Ellatrivia
Limatula	Tanea
*Parathyasira	*Friginatica (Sulconacca)

*Condylocuna	Austrosassia
*Marama (Hina)	*Haurokoa
*Kuia	Gegania
Notocorbula	Mathilda (Opimilda)
Verticordia (Spinosipella)	(?) Notosinister
Dentalium (Fissidentalium)	Cirsotrema
Cadulus (Polyschides)	*Liratilia
Poirieria	Pterynotus
*Xymene	*(?) Pervicacia
Coluzea	*Inglisella
*Austrofusus (s.str.)	Turbonilla
Fusinus	*Pyrgiscilla
Volvarinella	Syrnola
Alaginella	Puposyrnola
*Waimatea	Sinuatodostomia
*Amalda (Alocospira)	*Maxacteon
Conus (s.l.)	Ringiculina
Gemmula	Philine
*Marshallaria (Zeatoma)	(?) Scaphander
*Zeacuminia	Clio

Most of the taxa listed above have substantial fossil records but two of the bivalves [viz. Parathyasira and Verticordia (Spinosipella)] are known only from McCullough's Bridge and from the Recent fauna.

(3) Taxa which are known in New Zealand only from the Arnold Series. These may be divided into two groups:

(a) Taxa so far recorded only from the Kaiatan, and mostly only from the Tahu Member or the Kapua Tuffs. The 17 taxa included

here are:

Erycina (Hemilepton)	Distorsio (Personella)
Fustiaria (Fustiaria)	*Mathildona
Entalina	Lathyrulus
*Cerithiella (Eumiopila)	*Fractolatirus
*Spinoseila	*Tahudrillia
*Cosmasyrinx (Tholosyrinx)	Plesiocerithium (s.l.)
Cordieria	*Parapepta
*Narona (Naronista)	Elodiamea
*Miplioderma (Eosirius)	

(b) Taxa also known from other stages of the Arnold Series. Of these, Pseudoportlandia alone is recorded from all Arnold stages; the other taxa are known only from the Bortonian and Kaiatan, but this probably reflects the paucity of Runangan molluscan faunas rather than absence of the taxa concerned. The following 16 taxa belong here:

Pseudoportlandia	Mitrella (Bastropia)
*Duplipecten	Cancilla (Fusimitra)
*Waikakahia	Conomitra
*Notoseila (Eoseila)	Ancillus
*Carinacca	Marshallena
*Tahunacca	*Notogenota
Neverita	Cochlespira (Tahusyrinx)
*Tahuscala	*Triploca

(4) The remaining 41 taxa form a rather heterogeneous assemblage. A few (e.g. Spelaenacca and Zexilia) appear in the Wangaloan, but most are first known from the Bortonian or Kaiatan. Some range up into the Taranaki Series (e.g. Latiarca) but the majority are last known from the Pareora or Southland Series, while

a few (e.g. Spirocolpus and Eoturris) do not outlast the Paleogene. These taxa form a "middle Tertiary" element in the McCullough's Bridge faunas.

*Nanonucula
*Notolimopsis
Cucullaea (Latiarca)
*Glyptoactis (Fasciculicardia)
Fustiaria (Gadilina)
Cadulus (Gadila)
*Benthastelena
*Spirocolpus
Dicroloma (s.l.)
Lachryma
*Archierato
Niso
Colubraria
*Falsicolus (Liracolus)
*Exilia (Zexilia)
Proximitra
Protoginella
*Waihaoia (s.str.)
*Micrancilla
*Eoturris
*Marshallaria (s.str.)
*Tahuia
*Parasyrinx (Lirasyrinx)
*Magnatica (Spelaenacca)
Sassia
Ficus
Pseudomalaxis
Opalia
Pliciscala
Hemiacirsa
*Notacirsa
Pterochelus
(?) Inquisitor
Borsonia
*Eoscobinella
*n.gen. aff. Syngenochilus
Unitas
Fusiaphera
*Anapepta (s.str.)
*Superstes
Hyalocylis

CHAPTER V

COMPARISON OF MOLLUSCAN FAUNAS FROM TAHU MEMBER AND KAPUA TUFFS WITH OTHER ARNOLD SERIES FAUNAS

1. BORTONIAN

Before discussing Bortonian molluscan faunas, it is necessary to make some comments on the Bortonian stage, particularly on the problem of recognising the unit away from the type locality. The Bortonian was proposed by Park (1918: 25) as a lower substage of the Waiarekan to include the marine beds (mostly glauconitic sands) between the coal measures (Ngaparan in Thomson's classification - Thomson 1916) and the pyroclastics ("Upper" Waiarekan) exposed in north-east Otago. The type locality is at Black Point, Bortons, in the Waitaki Valley, where coal measures are overlain by about 180 ft (55 m) of sands and greensand (Tapui Glauconitic Sandstone - Gage 1957) constituting the Bortonian stage, in turn overlain by calcareous sandstone and hard limestone which is presumably a lateral facies of the Otekaike Limestone (Duntroonian-Waitakian). [Thickness given by Park (1918: 34-5); Gage (1957: 29) states that the thickness of Tapui Glauconitic Sandstone "cannot be more than about 50 ft"]. Shallow-water Mollusca (listed by Olson in Gage 1957: 111-3) occur in a hard calcareous sandstone band 30 ft (9 m) above the coal-measures (Park 1918: 33); the rest of the unit is unfossiliferous.

Allan (1926b: 324) proposed the Waimateian Stage for post-Wangaloan, pre-Ototaran marine beds exposed in the Waihao Valley (i.e. to include the whole of the Waihao Greensands), subdividing it into

two substages on the basis of its molluscan faunas. The lower unit, which was represented by all of the Waihao Greensands up to the "phosphatic" band at McCullough's Bridge, was correlated with Park's Bortonian, and the upper unit became a new substage, the Tahuian. Allan (1926c: 285) pointed out that fossils from Bortons were poorly preserved and that the substage would rest on much firmer paleontological grounds if it was based on the well-preserved molluscs from the Waihao district. This was later stated more explicitly by Allan (1933: 88) who defined the Bortonian as "the interval of time represented by the deposition of the lower greensands and sandstones in the Lower Waihao Valley, and as well such periods as may be represented therein by non-deposition or erosion". Lists of characteristic Bortonian molluscs were given by Allan (1926c: 289; 1933: 88) and Marwick (1931: 3).

During the 1930s, Foraminiferida gradually replaced Mollusca as the prime biostratigraphic tools in the New Zealand Cenozoic, and the paucity of microfossils in the Lower Waihao Greensands led Finlay and Marwick (1940: 106) to suggest that the section at Hampden Beach, North Otago, with its rich micro- and macrofaunas would make a better "standard section" for the Bortonian. Hornibrook (in Fleming 1959: 50) has pointed out that "no formal proposal for a standard section has found general acceptance" and it is probably best to regard the Hampden section as a "provisional parastratotype" only (Edwards 1971: 399). Unfortunately, there is no definite evidence (except for the presence of certain molluscs) to support the view that the Bortonian stratotype is equivalent in whole or even in part to the "Bortonian" beds at Hampden or to any of the numerous localities in North Otago and South Canterbury with rich molluscan faunas that have traditionally been assigned a "Bortonian" age (e.g. Waihao Downs, Kakahu, Opuha

River, Ashburton River, etc.). Foraminifera are of little use for correlating these localities for they are absent from Bortons itself and rare or absent at the others (with the notable exception of Hampden). Correlation with the Bortonian is instead made on the presence of certain distinctive molluscan taxa including Monalaria concinna (Suter), Fascioplex spp., Athleta necopinata Suter and Speightia spinosa (Suter). All of these have been recorded from the thin fossiliferous band at Bortons (Olson in Gage 1957: 111-3) but their presence in a fauna is scarcely good evidence for assigning it a Bortonian age when it is realised that we know nothing of the lower stratigraphic limit of any of these taxa. There is, however, one piece of evidence which suggests that the fossiliferous band at Bortons is considerably older than most, if not all, of the provisional stratotype at Hampden.

Elsewhere in this study (p. 178) it is suggested that the smooth pecten Lentipecten parki Marwick, originally described from Hampden and recorded from a number of Bortonian and Kaiatan localities, is a Duplipecten that has evolved from D. waihaoensis (Suter) by loss of the left valve radial costae. In the section along the South Branch, Waihao River near "Waihao Downs", Duplipecten waihaoensis is present in the Waihao Greensands exposed in the abandoned railway cutting and in the river cliffs c. 300 m downstream, but is replaced by D. parki in stratigraphically much higher beds (probably near the top of the Lower Waihao Greensands) about 1 km further downstream. Duplipecten waihaoensis has been recorded from Bortons (Olson in Gage 1957: 111) but is not known from Hampden where D. parki is present about 10 m above the base of the Hampden Formation (writer's observation) and possibly much lower in the section. If it is accepted that the bioseries D. waihaoensis-D. parki is a simple

phyletic lineage, then it must be concluded that the fossiliferous bed at Bortons and the greater part of the Lower Waihao Greensands in the Waihao Downs section are significantly older than at least the upper part of the provisional Bortonian parastratotype at Hampden. This raises serious doubts about the status of the Bortonian stage, for there seems little point in retaining a chronostratigraphic unit that cannot be recognised with any confidence away from its type locality. A wiser move would be to drop the Bortonian entirely and to propose a new stage with Hampden (or a more suitable section) as stratotype. Further discussion of this topic is, however, beyond the scope of this study and for the time being it has been decided to accept the Bortonian as a stage as traditionally defined by molluscan faunas from such localities as Waihao Downs, Kakahu, Pahi, etc.

(1) Waihao Downs

Glauconitic and micaceous sands comprising the Lower Waihao Greensands (which are at least in part Bortonian) are well exposed in both branches of the Waihao River upstream from Waihao Forks. There are a few records of macrofossils from Waihao Forks itself [e.g. the types of Waihaoia suteri Marwick and Zemacies hamiltoni (Hutton] but nearly all of the supposedly Bortonian molluscs described or recorded from the Lower Waihao Valley are from the South Branch near "Waihao Downs" station. Part of McKay's collection GS 479 from the "marly greensands" may be from this area (see discussion on early collections) but the first well-localised collections were those made by J.A. Thomson in 1913. These provided the types of ten species of molluscs described by Suter (1917), including such important species as Monalaria concinna and Athleta necopinata. Suter incorporated his identifications of Thomson's material in two lists of molluscs

from the Waihao (Suter 1921: 65, 65); unfortunately, these also include identifications based on two collections made by McKay (GS 479 and 480), probably from different localities and horizons. Except for a short list of species from the abandoned railway cutting (Olson in Gage 1957: 111-3) the only other list of Waihao Downs molluscs is that given by Allan (1926c: 289); this includes only 38 species, but apart from some changes in nomenclature, the identifications are mostly quite reliable.

The writer collected in the Waihao Downs area from three distinct localities:

(a) Eastern end of abandoned railway cutting c. 600 m northwest of "Waihao Downs" homestead (GS 9886) and stratigraphically similar beds exposed in river cliffs on right bank for about 200 m downstream (GS 9956). Grid reference S127/487038 (1966 ed.).

(b) High cliffs on right bank at first major bend downstream from railway cutting (GS 11148). This is probably the "Waihao Downs" locality of most previous authors. Grid reference S127/492043.

(c) Mouth of small steep gully entering Waihao River on left bank at the third major bend downstream from the railway cutting (GS 11216). Grid reference S127/503043).

The locality marked "fossils" on Allan's map (1926c: 266) and noted by him (p. 288) as containing "an excellent molluscan fauna" could not be relocated during the present study. It appears to be badly overgrown and inaccessible.

Localities (a) and (b) are at approximately the same stratigraphic horizon, although the molluscan assemblage at (b) is considerably more varied than that from (a). Locality (c) however is

stratigraphically much higher than the other two, and appears to be near the top of the Lower Waihao Greensands. The combined molluscan fauna from these three localities (together with published "Waihao Downs" records), a total of 70 species, is compared with the McCullough's Bridge faunas in the following paragraphs:

(i) Comparatively few species are common to the Waihao Downs and Tahu Member faunas. Allan (1926c: 289) noted that eight Bortonian species (out of 38) persisted into the "Tahuian". In the present study 14 species are found to be common to the two faunas: Saccella semiteres, Cucullaea (Latiarca) waihaoensis, Duplipecten parki, Eucrassatella australis, Tanea praeconsors, Neverita pontis, Carinacca allani, Tahunacca haasti, Globisinum elegans, Gegania olsoni, Poirieria cf. primigena, P. denticulifera, Mitrella (Bastropia) mackayi and Amalda (Gracilispira) morgani. /An additional species, Cancilla (Fusimitra) hectori, which was described from "Waihao, near the coal mine", should probably be added to this list/. The Jacard Similarity Coefficient (see Table 5) for the two faunas is only 0.06.

The molluscan fauna from the Kapua Tuffs is even less like the Waihao Downs fauna. The following species are recorded from both faunas: Eucrassatella australis, Tanea praeconsors, Tahunacca haasti and Globisinum elegans. The Kapua Tuffs fauna is still poorly known but the proportion of species common to the faunas will probably not increase significantly since the two units differ considerably in age and lithofacies.

(ii) Four genus-group taxa (Monalaria, Fascioplex, Athleta and Speightia) occur at all three Waihao Downs localities but have not been collected from the Tahu Member, nor indeed, from any post-

Locality	Stage	N_2	C	J
Waihao Downs	Bortonian	70	14	0.06
Hampden	"	101	20	0.08
Lorne	Kaiatan	104	14	0.06
Port Elizabeth	"	48	8	0.04
Trig. M, Totara	Runangan	48	8	0.04
Bridge Pt	"	47	2	0.01

Table 5. Quantitative comparison of Tahu Member molluscan fauna with other important Arnold Series faunas. The Jacard Similarity Coefficient (J) is given by the formula -

$$J = \frac{C}{N_1 + N_2 - C}$$

where N_1 is the number of species in Tahu Member (167)

N_2 " " " " " " compared fauna

C " " " " " common to the two faunas.

Bortonian locality. Some or all of these taxa are represented in virtually all "Bortonian" molluscan faunas.

(iii) In at least three respects the fauna from locality (c) is closer to the Tahu Member fauna than those from (a) or (b):

The Limopsis at locality (c) is small and rather fragile, resembling L. waihaoensis from McCullough's Bridge, and belongs in a different group from the larger, more robust L. campa Allan common at localities (a) and (b).

Duplipecten waihaoensis (Suter), present at localities (a) and (b), has not been collected from locality (c) where it is replaced by its probable descendant D. parki, which ranges up into the Tahu Member at McCullough's Bridge.

The Sassia at locality (c) closely resembles Sassia n.sp. from the Tahu Member and is quite distinct from S. decagonia (Finlay) which occurs at locality (b).

The occurrence of Duplipecten parki rather than D. waihaoensis at locality (c) is probably due to this locality's relatively high stratigraphic position, but the other two discrepancies are likely to be the result of ecological factors, particularly depth of deposition. The stratigraphic succession in the Waihao district indicate gradual transgression from at least late Dannevirke time to Whaingaroan (see p. 35), so the beds at locality (c) were probably deposited in deeper waters than those at localities (a) and (b).

(2) Hampden Beach

The fossil locality at Hampden Beach (Onekarara), about 60 km S of McCullough's Bridge, was one of the first in New Zealand to be collected by geologists. In fact the earliest published illustration

of New Zealand Cenozoic molluscs (Mantell 1850) includes a specimen of a Dentalium (later named D. centenniale Marwick, 1942) collected by Walter Mantell in 1848. However, no Hampden molluscs were named until Suter (1915: 50) described a verticordiid as Trigonia neozelanica. Shortly afterwards, Patrick Marshall (1919) described 27 new species of molluscs in a short paper on the Hampden fauna. Other Hampden molluscs were described in papers by Marshall and Murdoch (1920, 1923), Laws (1935b, 1937, 1938) and Marwick (1942, 1943).

The Bortonian fossils from Hampden come from the Hampden Formation (McKay 1877: 52; Brown in Fleming 1959: 118-9), a medium-grey micaceous siltstone, highly glauconitic near the base, exposed for several hundred metres north and south of the mouth of Kakaho Creek. Macrofossils, many of them badly crushed by sediment compaction, occur only sporadically through the unit and a representative collection requires numerous visits to the locality. Many of the molluscs described by Marshall are still known only from the type material.

Lists of Hampden molluscs have been given by Mantell (1850: 331) (this seems to include a number from the Pliocene and Pleistocene of Wanganui), Hutton (in Hutton and Ulrich 1875: 59-61; 1887a: 426-7), Park (1905: 506) and Marshall (1917: 464; 1919: 235; 1923: 117). Marshall's last list includes 96 names, but several of these are synonyms. An updated list of 92 species, which includes Marshall's identifications brought into line with modern nomenclature, together with additional species recorded by subsequent workers, was compiled by Dr J. Marwick for a Geological Survey Bulletin (as yet unpublished) on the Moeraki Subdivision. This formed the basis for

the writer's checklist (totalling 101 species) which includes new records based on his own collecting.

Marshall (1923: 118, 119) and Allan (1926c: 292-3) both commented on the similarity of the Hampden and McCullough's Bridge molluscan faunas. The former worker stated that 44% of the Waihao species occur also at Hampden, but Allan gave a much lower figure of only 27%, a value that he thought was rather conservative as he had not personally studied the Hampden fauna. Marshall (1923: 119) concluded on both paleontological and stratigraphical grounds that the McCullough's Bridge fauna was "distinctly younger" than that from Hampden, but Allan thought that the two faunas were of similar age (i.e. Tahuian). Allan was partly influenced by the relatively low number of species common to Hampden and Waihao Downs (which he had correlated with the Bortonian). Marwick (1931: 3), however, included Hampden in a list of Bortonian fossil localities, and this correlation has been accepted by all subsequent workers. Srinivasan (1966: 509) revived the whole problem by suggesting that the majority of McCullough's Bridge molluscs were in fact from the Bortonian part of the section, thus explaining the supposed similarity of the Hampden and "Tahuian" faunas. This was refuted by Maxwell (1967: 1169) who noted that the faunal similarity "is almost certainly due to a similarity in facies". A careful examination of the two faunas indicates that the alleged similarity is not as great as has been maintained.

The following species appear to be common to Hampden and the Tahu Member: Cucullaea (Latiarca) waihaoensis, Bathyarca bellatula, Notolimopsis hampdenensis, Duplipecten parki, Notoseila (Eoseila) attenuissima, Dicroloma zelandica, Proterato (Archierato) antiqua,

Carinacca allani, C. waihaoensis, Tahunacca haasti, Globisinum elegans, Notosinister aoteaensis, Coluzea climacota, Volvarinella aveniformis, Gemmula duplex, Eoturris complicata, Marshallena neozelanica, Zemacies marginalis, Zeacuminia tahuia, Pyrgiscilla hampdenensis and Superstes marshalli. Although this list seems impressive, the Jacard Similarity Coefficient for the two faunas is only 0.08. (By comparison, there are 18 species common to Hampden and Waihao Downs, giving a Jacard Coefficient of 0.12).

Several genus-group taxa which occur at Hampden have not been recorded from the Tahu Member. The more important of these are Monalaria, Priscoficus, Fascioplex and Speightia, none of which are known from post-Bortonian faunas.

In addition there are several taxa which are probably absent from McCullough's Bridge because of ecological factors, e.g. "Verticordia", Kurinuia, Tipua, Ancillina and Insolentia. All of these are known from post-Kaiatan faunas, and Tipua is recorded from the Kaiatan at Port Elizabeth. On the other hand, a number of taxa are common in the Tahu Member but unknown from Hampden, e.g. Notocorbula, Zeacolpus, Tanea, Polinices (Polinella), Friginatica (Sulconacca), Wangaloa, Lathyrulus, Conomitra, Amalda (Gracilispira) and Cordieria. Most of these are known from Bortonian faunas elsewhere and their absence from Hampden suggests that the Hampden Formation may have been deposited under somewhat deeper conditions than the Tahu Member.

(3) Other Bortonian localities

Rich molluscan faunas assigned a Bortonian age are known from many other localities in North Otago and South Canterbury, the most important being Black Point, Bortons (type Bortonian), a number of localities in the Ngapara and Tokarahi districts (see lists by Marwick

and Olson in Gage 1957: 111-3), upper Waihao Valley near "Pentland Hills", Pareora R., Opuha R. and Kakahu. Most of the fossils are from shallow water shellbeds, usually closely associated with coal measures. These faunas include some or all of the "typical" Bortonian taxa recorded from Hampden and Waihao Downs (e.g. Monalaria, Fascioplex, Speightia) as well as many shallow-water bivalves, including Glycymeris (Glycymerita), Cubitostrea, large Eucrassatella australis, Hedecardium, Tellinidae and Dosiniinae, none of which occur in the Kaiatan beds at McCullough's Bridge. These faunas have even less in common with the Tahu Member and Kapua Tuffs faunas than those from Waihao Downs or Hampden, and are not discussed further.

The molluscan fauna from Pahi, Northland, described by Fleming (1950), is also assigned a Bortonian age. This fauna is of shallow-water aspect (Tellinidae, common carditids, Offadesma, Cypraeidae), but the following species recorded by Fleming indicate some ties with the Tahu Member fauna: Saccella semiteres, Cucullaea cf. waihaoensis, Notocorbula aff. humerosa (Hutton) (= N. allani n.sp.), Falsicolus cf. solida and Marshallaria cf. spiralis.

2. KAIATAN

(1) Lorne.

Apart from the McCullough's Bridge faunas, the only sizeable Kaiatan molluscan fauna known from North Otago and South Canterbury is from the Waiareka Volcanic Formation at Williams Bluff, Lorne, 30 km S of McCullough's Bridge. The locality has been described by Marwick (1926b: 308) and by Edwards (in Stradner and Edwards 1968: 6-8), the latter author also providing a stratigraphic column. According to Marwick, macrofossils come from tuffaceous conglomerate exposed

at two localities on the hillside near Lorne railway station (now disused); "A", which is probably a slumped block, and "B", which is in situ. Most collections from Lorne are from the former locality.

Lorne was first collected by Thomas Esdaile in about 1886; collection GS 831 includes material from this locality together with some specimens from other horizons (see Marwick 1926b). The locality was recollected by Marwick in 1921, who described 19 new species and assigned the fauna a late Eocene or Oligocene age (Marwick 1926b). Other Lorne molluscs have been described by Beu (1970a), Laws (1932, 1935c), Marwick (1923, 1924a) and Maxwell (1966). In addition, five species of gastropods described by Finlay (1924, 1930a), supposedly from Kakanui, are probably from Lorne (Maxwell 1968a).

The Lorne molluscan fauna is strikingly different from that of the Tahu Member. Epifaunal molluscs are common and include such bivalves as arcids (Arca, Arcopsis), Grandaxinea, limids (Limatula, Limea) and pectens (Chlamys, Serripecten), patelliform gastropods (acmaeids, Emarginula, Hipponyx, Capulus, Sigapatella) and others preferring a firm substrate (Bolma, Astraea, Xenophora, cymatiids) occur together with rissoids, cerithiopsids and abundant pteropods (Spiratella, Hyalocylis and Clio). In contrast to the Tahu Member, infaunal bivalves, scaphopods and such gastropods as naticids, epitoniids, olivids, turrids and cancellariids are rare or absent. The deposit probably represents a submarine slump that accumulated on the flank of a volcanic seamount in at least moderate depths. /The Bolma occurring at Lorne is very similar to B. recens (Dell) from 540-680 m, Kiwi Seamount, north of New Zealand (Beu & Ponder, in press)/.

Of 104 species of molluscs recorded from Lorne (based on

published records augmented by material collected by the writer) only 14 occur also in the Tahu Member. These are Nemocardium (Pratulum) semitectum, Zeacolpus lornensis, Pareora sublaevis, Lachryma vulcania, Taniella notocenica intermedia, Polinices (Polinella) esdailei, Austrosassia cyphoides, Haurokoa marwicki, Gegania olsoni, Xymene apipagodus, Liratilia pulchella, Cancilla (Fusimitra) hectori, Waimatea inconspicua and Clio n.sp. The Jacard Similarity Coefficient for the two faunas is only 0.06. However, it should be emphasised that several Lorne species are closely related to Tahu Member species, e.g. Condylocuna n.sp. from Lorne is similar to C. subaequilateralis, Spirocolpus tophinus (Marwick) is possibly conspecific with S. waihaoensis, Tahuia esdailei (Marwick) resembles T. formosa, and Superstes phoenix Finlay and Marwick is like S. marshalli.

Similarities between the Kapua Tuffs and Lorne faunas are less marked than might be expected. The following species are common to the two faunas: Zetela vulcania, Zeacolpus lornensis, Polinices (Polinella) esdailei, Austrosassia cyphoides (identification uncertain), Liratilia pulchella, Cancilla (Fusimitra) hectori, Waimatea inconspicua, Spiratella n.sp. B and Hyalocylis sp. The molluscan fauna from the Kapua Tuffs is still rather poorly known, however, and will probably come to resemble that from Lorne with further collecting.

(2) West Coast, South Island

On the west coast of South Island the Kaiatan is represented, for the most part, by massive, dark grey siltstone or mudstone generally referred to as the Kaiata Formation (or Mudstone) or, in the Murchison district, as the Maruia Formation. A few poorly preserved molluscs have been collected from near Murchison, Reefton and Lyell, but only two faunas of any size are known to the writer, one

from Port Elizabeth, the other from the Buller Valley near Inangahua.

Siltstones of the Kaiata Formation are well exposed west of Rapahoe, Port Elizabeth, about 8 km N of Greymouth and some 250 km N of McCullough's Bridge. Srinivasan (1966: 509) referred to this section as the "type Kaiatan" and though it has not so far been formally designated as the Kaiatan stratotype, it would be a better choice than the name-bearer, Kaiata Ck. The basal portion of the Kaiatan is not exposed at Port Elizabeth, however, and the beds are substantially younger than the Tahu Member at McCullough's Bridge (Srinivasan 1966: 509; Edwards 1971: 402-3). Macrofossils (chiefly molluscs but also corals and crinoids) are generally sporadically distributed through the unit, but collection GS 4872, made by M. Gage and H.W. Wellman in 1949, is apparently from a shell-rich pocket high in the Kaiatan part of the section.

The writer has identified 45 species of molluscs in GS 4872. The larger shells are badly crushed but the smaller specimens are usually well preserved though many have been damaged during extraction. Species considered to be common to the Tahu Member and GS 4872 are Ledaspina knudseni, Dentalium (Fissidentalium) delli, Tahunacca haasti, Austrofusus bicarinatus, Falsicolus (Liracolus) solida, Exilia (Zexilia) waihaoensis, Waimatea inconspicua and Zemacies marginalis. The Jacard Similarity Coefficient is 0.04. The presence of such taxa as Pseudoportlandia, Conomitra, Amalda (Gracilispira), Ancillus and Gemmula n.sp. aff. waihaoensis increases the similarity to the Tahu Member fauna, although they are all different species from the Waihao forms. On the other hand the Port Elizabeth fauna includes several distinctive taxa that do not occur at McCullough's Bridge, e.g. Procardia, Euciroa, Tipua /closely related to T. tricincta (Marshall) from Hampden/,

Uberella aff. cicatrix Marwick and Microdrillia. The differences between the two faunas may be partly because GS 4872 is somewhat younger, but a difference in depth of deposition is a more likely cause. Srinivasan (1965: 301) suggested that by late Kaiatan times the Kaiata Formation at Port Elizabeth was being deposited at depths of "a maximum of at least 150-300 m". Elsewhere in this study it is suggested that the Tahu Member was deposited at depths of 100-200 m.

When it is better known, the Kapua Tuffs fauna will probably prove a closer match for GS 4872. The following species occur at both localities: Dentalium (Fissidentalium delli, Tahunacca haasti and Waimatea inconspicua. In addition, the new turrid subgenus Tholosyrinx (of Cosmasyrinx) is present in both faunas but has not been recorded from the Tahu Member.

The other Kaiatan macrofauna from the Kaiata Siltstone considered in this study is GS 3301, road-cutting on Inangahua-Westport Road near Melrose, collected by Gage and Wellman in 1944. The shells are all rather small (generally less than 20mm) and often badly crushed though otherwise well-preserved. Of 24 species identified by the writer, only two, Waimatea inconspicua and Ringiculina tenuilabrum, are also present in the Tahu Member at McCullough's Bridge. However, the badly crushed specimen of Tahunacca from GS 3301 may be conspecific with T. haasti and the Parvamussium present there may belong to one of the three species recorded from McCullough's Bridge. Further affinities with the Tahu Member are suggested by the presence of Pseudoportlandia, Fustiaria (Gadilina), Spinoseila, Ancillus, Amalda (Micrancilla), Tahuia and Cordieria, all of them, however, represented by species which differ from the McCullough's Bridge species. Moderate similarity to the Kapua Tuffs molluscan

fauna is suggested by the presence in both of Waimatea inconspicua, the subgenus Parasyrinx (Lirasyrinx) and most of the genus-group taxa listed above.

3. RUNANGAN

Runangan molluscs are poorly known and few localities that yield more than one or two species have so far been found. Those discussed below are all from North Otago from horizons in the Waiareka Volcanic Formation or the overlying Totara Limestone.

Calcareous tuffs in the Totara Limestone near the summit of Trig. M Totara (about 8 km SW of Oamaru) have yielded the best-known Runangan macrofauna. The locality was first collected by J.A. Thomson and G.H. Uttley in 1914 and by J. Park in 1916 (Park 1918: 73-4), and although it has been collected by a number of subsequent workers the fauna is still rather poorly documented. To date, only five species of molluscs have been described from Trig. M (Suter 1917: 3; Laws 1935b). The molluscan fauna was listed by Suter (in Park 1918: 74; Suter 1921: 88) and by Olson (in Gage 1957: 115). Molluscs from Trig. M are mostly rather small (less than 10 mm) and fragile. As noted by Laws (1935a: 19) the fauna resembles that from Lorne in some respects [occurrence in both of Arcopsis januaria (Marwick), Grandaxinea lornensis (Marwick), Limatula trulla Marwick, Argalista proimpervia Laws, Spirocolpus tophinus (Marwick), etc.] but differs in lacking many of the larger epifaunal gastropods so characteristic of that locality (e.g. Astraea, Bolma, Falsicolus, Cymatiidae). It does not strongly resemble the Tahu Member fauna; of 48 species recorded from Trig. M (published records plus material collected by the writer), only eight occur at both localities, giving

a Jacard Similarity Coefficient of 0.04. These are Limopsis waihaoensis, Nemocardium (Pratulum) semitectum, Zeacolpus lornensis, Pareora sublaevis, Strombiformis waihaoensis, Polinices (Polinella) esdailei, Taniella notocenica intermedia and Lachryma vulcania. Zeacolpus lornensis, Polinices (Polinella) esdailei and Hyalocylis sp. are common to Trig. M and the Kapua Tuffs.

A moderately large Runangan molluscan fauna has been collected from calcareous tuffs and agglomerate in the upper part of the Waiareka Volcanics at Bridge Pt, about 15 km S of Oamaru. This is the type locality of the bivalve Cardilona bensoni Marwick, but apart from Marwick's record of the pecten "Chlamys" venosa (Hutton) (Marwick 1943: 181) there is no other published information on the molluscs from Bridge Pt. The fauna, as collected by the writer, has a number of species in common with those from Lorne and Trig. M /e.g. Arcopsis januaria, Nemocardium (Pratulum) semitectum, Emarginula n.sp., Argalista proimpervia, Zeacolpus lornensis/ but differs in the presence of Lima n.sp., Isolimea n.sp., "Chlamys" venosa, Marama (Hina) n.sp. aff. tumida (Marshall) and relatively common Danilia neozelanica Laws (very rare at its type locality, Trig. M). Of 47 species recorded by the writer only two, N. semitectum and Z. lornensis, are also definitely known from the Tahu Member, but this figure would probably be increased if better material of some of the Bridge Pt species was available.

A few Runangan molluscs have also been recorded from the Oamaru Diatomite in the Weston area, about 1 km S of Lorne (Maxwell in Edwards and Hornibrook, in prep.). The molluscs are sparse and, except for a few calcitic species (Parvamussium, Dimya), are represented only by casts and moulds. The small fauna includes the

following bivalves recorded from the Tahu Member at McCullough's Bridge: Pseudoportlandia tahuia, Limopsis waihaoensis and Nemocardium (Pratulum) semitectum. The substrate was undoubtedly much softer than at Lorne, Trig. M or Bridge Pt, and probably more like that at McCullough's Bridge, which would help to account for the greater similarity between the faunas.

In summary, it may be stated that the molluscan faunas from the Tahu Member and Kapua Tuffs have little similarity at the species level to other Arnold Series faunas but have moderate similarity at the genus-group level. This genus-group similarity tends to be less marked in the Bortonian faunas due to the presence of taxa which are not known from post-Bortonian localities. In general, however, differences between known Arnold Series faunas seem to be due less to differences in age than to ecological factors.

CHAPTER VI

EXTERNAL AFFINITIES OF NEW ZEALAND UPPER EOCENE MOLLUSCAN FAUNAS

Upper Eocene molluscan faunas have been described from many parts of the world, including Europe, North America, West Africa, Egypt and Indonesia, but these show only limited similarity at the genus-group level to the known New Zealand faunas (totalling about 350 species) of this age. Such similarities as exist are mostly in long-ranging, widespread (if not cosmopolitan) taxa and the species concerned show little evidence of close relationships. In fact, the local Upper Eocene faunas exhibit a strong degree of endemism; of 145 genus-group taxa recorded from the Tahu Member in this study, about 40 are known only from New Zealand, and another 30 only from New Zealand and south-eastern Australia. (Comparable figures for the other large Upper Eocene molluscan fauna from New Zealand, i.e. Lorne, are 100, 22, 21). The discovery of new Kaiatan or Runangan fossil localities might well alter this picture of strong endemism, but the writer's experience with pre-Kaiatan (mostly Bortonian) faunas suggests that any numerical increase in the number of "exotic" taxa recorded would be compensated for by the discovery of endemic taxa previously unrecorded from pre-Oligocene beds. In the last few years a number of molluscs with overseas affinities (e.g. Callistotapes, Liotina, Rimella, Typhis, etc.) have been found in Bortonian faunas, but the same work has brought to light Bortonian species of such endemic or S.W. Pacific taxa as Taras (Zemysia), Scalpomactra, Maorimactra, Macomona and Kuia, none of which was formerly known from the New Zealand Eocene.

Most of the "exotic" taxa recorded from the New Zealand Upper Eocene are known from Bortonian, if not older, faunas and were well established in the New Zealand region by Kaiatan-Runangan times (see discussion earlier in this section, also Table 4). This is true even for those taxa with warm-water (mostly Indo-Pacific) affinities. Several authors (e.g. Finlay and Marwick 1940: 129; Fleming 1962: 72; Beu 1966: 181; Maxwell 1971: 764-6) have noted that many warm-water mollusca are first known from the Bortonian, but in the writer's opinion this is due partly to the lack of suitable lithofacies of post-Wangaloan, pre-Bortonian age. (The recent discovery of Spondylus in Mangaorapan tuffs at White Ck, North Canterbury, gives some support to this idea; the genus was previously unknown in the New Zealand Cenozoic prior to the Bortonian). There is no evidence for any comparable influx of warm-water, exotic molluscs in the Kaiatan or Runangan, although a few taxa /e.g. Pecchiolia, Fustiaria (s.str.), Entalina, Distorsio (Personella), Cordieria, etc./ are so far known only from one or both of these stages. This seems to parallel the situation in the Paris Basin where, according to Davies (1934: 118) "the influx of Tethyan forms had practically ceased by the end of Lutetian time".

Although warm, probably subtropical, conditions prevailed in southern New Zealand during the Upper Eocene (see discussion on palaeoclimates), this region probably lay close to the southern edge of the Tethyan realm or even beyond it. This is suggested by the strong endemism of the molluscan faunas noted above and by the absence of many taxa, mostly of Tethyan affinities, that are present in Eocene faunas at similar latitudes in Europe. The more important of these taxa are Vulsella, Codakia, Trapezium, Meiocardia, Cultellus,

Venericor, Pitar (s.str.), Angaria, Velates, Neritopsis, Sigmesalia, Terebralia, Clava, Strombus (s.l.), Terebellum, Aporrhais, Naticarius, Globularia, Crommium, Sconsia, Siphonochelus (Laevityphis), Melongena, Clavilithes (Clavellofusus), Oliva, Pseudoliva, Vasum, Tudicla, Harpa and Conorbis. (Compare Fleming 1967: 117).

Some of these taxa may eventually be discovered in Kaiatan or Runangan faunas, but the writer doubts that such discoveries would materially alter the evidence for New Zealand's comparative isolation during the Upper Eocene.

As might be expected on purely geographical grounds, the strongest external affinities shown by the New Zealand Upper Eocene molluscan faunas are with those from south-east Australia. As noted above, an appreciable proportion of the genus-group taxa recorded from the Tahu Member and from Lorne have south-east Australian affinities but in fact, the relationships are often somewhat closer, though not necessarily at a specific, taxonomic level. Some of the genus-group taxa endemic to the two areas have not so far been recorded from the Australian Cenozoic (e.g. Parathyasira, Benthastelene) but most of them have some sort of fossil record, in many cases extending back to the Upper Eocene.

In a series of papers published in the latter part of last century Ralph Tate described or recorded some 200 species of molluscs from Upper Eocene (Aldingan) localities in Victoria and South Australia. Unfortunately for workers without access to comprehensive collections, it is often difficult to tell if Tate's species are closely related to New Zealand forms. Dr N.H. Ludbrook's revision of Tate's molluscs will do much to rectify this situation, but is still at too early a stage to have had much effect. A

general lack of faunal studies on the Australian Paleogene and the absence of an up-to-date faunal list for any Upper Eocene locality makes comparative studies even more difficult.

In the present comparative study, the literature was searched for any Australian Upper Eocene molluscs that seemed to be closely related to species recorded from the Kaiatan and Runangan. This study was aided considerably by collections made by Dr A.G. Beu in October 1971 from the following localities:

(a) Brown's Creek, Johanna, Otway Basin. Correlated with Kaiatan (T.A. Darragh pers. comm. to Dr Beu).

(b) Glen Aire Clay, Station Ck, Cape Otway (probably the "Cape Otway" locality of early workers). About equivalent to Runangan.

(c) Blanche Pt Marl, Blanche Pt, Port Willunga (= "Aldinga" of early workers). Equivalent to Kaiatan-Runangan.

A list of the related species from Australia and New Zealand given in Table 6 will undoubtedly be expanded considerably as the Upper Eocene faunas in both countries become better known. The similarities are quite strong, but the differences are at least equally significant. This is particularly true in the well-studied Turridae. The Australian faunas include Conorbis, Comitas, Apiotoma, Mauidrillia, large species of Borsonia (e.g. B. protensa Tate), Etrema, and several daphnellines, including Asperdaphne, Syngenochilus (s.str.) and n.gen. aff. Eubela, none of which are so far known from coeval beds in New Zealand. On the other hand, the following taxa are present in the New Zealand but not, apparently, in the Australian Upper Eocene: Gemmula, Eoturris, Marshallena, Notogenota, Tahuia, Parasyrinx (Lirasyrinx) and Eoscobinella.

New Zealand species	New Zealand Upper Eocene localities: Tahu Member	Kapua Mbr	Lorne	Trig. M, Potaka	Bridge Pt	Oamaru Diatomite	Australian species	Australian localities: Brown's Ck	Cape Otway (Station Ck)	Aldinga (Blanche Pt)	Adelaide Bore
Saccella semiteres (Hutton)	X	-	-	-	-	X	S. chapmani (Finlay)	X	-	X	-
Arcopsis januaria (Marwick)	-	-	X	X	X	-	A. dissimilis (Tate)	-	-	X	X
Notogrammatodon inexpectatus (Maxwell)	-	-	X	-	-	-	N. cainozoica (Tate)	-	-	-	X
Limopsis waihaoensis Allan	X	-	-	X	-	X	L. chapmani Singleton	X	-	X	X
Limea allani n.sp.	X	-	-	-	-	-	L. multiradiata Tate	-	-	X	-
Isolimea n.sp.	-	-	-	-	X	-	I. alticosta (Tate)	-	-	-	X
Dimya n.sp.	-	-	-	-	-	X	D. sigillata Tate	-	-	X	X
Nemocardium (Pratulum) semitectum Marwick	X	-	X	X	X	-	N. hemimeris (Tate)	-	-	-	X
Pustiaria (Gadilina) maoria n.sp.	X	X	-	-	-	-	Pustiaria n.sp.	X	X	-	-
Spirocolpus waihaoensis (Marwick)	X	X	-	-	-	-	S. aldingae (Tate)	X	X	X	X
S. tophinus (Marwick)	-	-	X	X	-	-					
Pareora sublaevis Maxwell	X	-	X	X	-	-	P. stylacris (Tate)	-	X	X	-
Niso neozelanica Suter	X	-	-	-	-	-	N. kimberi Pritchard	-	X	X	-
Strombiformis waihaoensis (Allan)	X	-	-	X	-	-	S. aff. danae (Tenison-Woods)	-	X	X	-
Proterato (Archierato) accola (Laws)	X	-	-	-	-	-	P. pyrulata (Tate)	-	X	X	X
Austrosassia cyphoides (Finlay)	X	?	X	-	X	-	Austrosassia sp.	-	X	-	-
Wangaloa ngaparaensis (Suter)	X	X	-	-	-	-	Wangaloa n.sp.	-	X	-	-
Pseudomalaxis asculpturatus Maxwell	X	-	-	-	-	-	Pseudomalaxis ?n.sp.	-	-	-	X
Pterynotus laetificus Finlay	X	-	-	-	-	-	P. calvus (Tate)	-	X	X	-
Xymene apipagodus Ponder	X	-	X	-	-	-	X. hypsellus (Tate)	-	X	X	X
Exilia (Zexilia) waihaoensis Suter	X	X	-	-	-	-	E. (Zexilia) n.sp.	-	X	-	-
Waimatea inconspicua (Hutton)	X	X	X	-	-	-	W. complanata (Tate)	-	X	-	X
Marshallaria (s.l.) n.sp.	X	-	-	-	-	-	Marshallaria sp.	-	X	-	-
"Syngenochilus" anceps n.sp.	X	-	-	-	-	-	"Syngenochilus" n.sp.	-	X	-	-
Triploca waihaoensis Marshall & Murdoch	X	-	-	-	-	-	T. ligata Tate	-	X	X	X
Hyalocylis sp.	-	X	X	X	-	X	H. annulata (Tate)	-	-	X	-

Table 6. List of selected New Zealand Upper Eocene molluscs with apparently closely related Australian species.

Reconstructions of SW Pacific paleogeography based on plate tectonic theories indicate that 30 m.y. ago, New Zealand was somewhat closer to Australia than it is now, though far from contiguous, and that except near the northern end of the Lord Howe Rise, the two areas were separated by oceanic crust formed during the Eocene (Griffiths and Varne 1972: fig. 4). The molluscan evidence certainly suggests that some sort of barrier, probably an area of deep water, prevented free interchange of all except a few forms (e.g. those with long-lived planktonic larval stages).

CHAPTER VII

NOTES ON MACROFOSSIL COLLECTIONS FROM WAIHAO GREENSANDS

1. EARLY COLLECTIONS

Although the Lower Waihao Valley abounds in landmarks of one sort or another, 19th century collectors seem to have been unable, or perhaps reluctant, to provide accurate locality details for their collections. Of the four collections discussed below, only GS 642 can be considered reliably localised; the others, all of which have provided type material for species described by Hutton, Suter and Marwick, are of uncertain provenance.

1. "Waihao" (or "Waiho") collected by J. von Haast in 1867. This is the type locality of Leda semiteres, Hutton, 1877, Cladopoda directa Hutton, 1877 (see Hutton 1888: 265 - no locality whatsoever is given for this species in Hutton 1877), Lunatia suturalis, Hutton, 1877, Mitra inconspicua Hutton 1885 (see Marwick in Allan 1926b: 341) and Clathurella rudis Hutton, 1885. No more precise locality details are given in either the 1877 or 1885 papers but in a later paper Hutton (1887b: 430) states that Haast's collection is from Waihao Forks. Of the five names given above only Lunatia suturalis (as Natica suturalis) appears in a list of fossils from Waihao Forks provided on pages 431-2 of this paper, but in yet another paper (1888: 265), Hutton notes that L. semiteres and C. directa are represented in the list by L. fastidiosa Adams and Teredo heaphyi Zittel respectively, and that M. inconspicua was inadvertently omitted.

The precise provenance of Haast's collection remains uncertain. Greensands exposed in the Waihao R. at the Forks belong to the lower (i.e. Bortonian) part of the Waihao Greensands and contain only sparse, poorly preserved molluscs. These beds seem unlikely to be the source of Haast's specimens, which it must be concluded were either from a locality in the vicinity of Waihao Forks that has so far escaped rediscovery, or from somewhat further afield, possibly at McCullough's Bridge about 3 km downstream. Saccella semiteres, Waimatea inconspicua and Cordieria rudis are all common in the Tahu Member at McCullough's Bridge and the last-named species is, in fact, unknown elsewhere. Waimatea inconspicua does not occur in the Lower Waihao Greensands where it appears to be replaced by W. amplexa Finlay. Saccella semiteres is present in both Bortonian and Kaiatan faunas from the Waihao Valley. The types of Cladopoda directa and Lunatia suturalis are lost and the identity of these species is uncertain, although Marwick (1924a:557) has assumed the latter species to refer to the Friginatica (Sulconacca) so common at McCullough's Bridge.

2. GS 479. "Marly greensands, Waihoa /sic/ River, Geraldine County, Canterbury. McKay 1880. Cretaceo-tertiary" (from original Geological Survey register in A. McKay's handwriting). No further locality details are given in either the register or in McKay (1882). This is the type locality of the following gastropods described by Suter (1917): Rapana neozelanica, Vexillum apicicostatum, Hemifusus (Mayeria) goniodes, Clavatula mackayi, Turris duplex and Surcula mordax. A figured paratype of Turris uttleyi Suter, 1917 is also from GS 479.

Finlay (1930a: 66-7) discussed the provenance of GS 479 and

concluded that the collection was composite, with material from two distinct horizons, one Bortonian, the other "Tahuian". He suggested that the holotypes of H. goniodes and C. mackayi were from the "Waihao Downs greensand" and the holotypes of S. mordax, T. duplex, the paratype of T. uttleyi and possibly the holotype of V. apicicostatum from a "Tahuian band or locality". The writer has re-examined the types of Suter's species and what remains of GS 479, and agrees that the collection is a mixed one. Two types of material are represented:

(a) The bulk of the collection consists of a hard calcareous glauconitic sandstone with poorly preserved, largely decorticated molluscs, including Limopsis cf. campa Allan, Monalaria sp. and Athleta necopinata Suter. The types of H. goniodes and H. neozelanica are of similar preservation. This material is almost certainly from the Lower Waihao Greensand, probably from the Waihao Forks - Waihao Downs area.

(b) The other specimens in GS 479 are loose shells with small amounts of adhering greensand matrix, agreeing closely with shells from the Tahu Member at McCullough's Bridge. The following molluscs are present: Dentalium (Fissidentalium) waihaoense n.sp., Amalda (Gracilispira) morgani, Zeacuminia tahuia and Cordieria rudis, all of which occur at McCullough's Bridge. The types of the remainder of Suter's species from GS 479 are similar in preservation and are probably from the same horizon. It is probable that this material is from McCullough's Bridge, but it is possibly from another exposure of Kaiatan beds, e.g. Haast's "Waihao Forks" locality.

3. GS 630. This locality is given in McKay's Geological Survey register as "Easdale's Collection Tenaraki Oamaru Otago"

(added after the page had been written - Marwick 1924b: 280) and by Suter (1921: 79) as "Teaneraki (Enfield), Oamaru District Geological Survey locality 630: Thomas Esdaile, circa 1886". GS 630 is the type locality for seven species of gastropods described by Suter (1917), viz. Sinum (Eunaticina) elegans, Fusinus climacotus, F. solidus, Exilia crassicostata, Turris bimarginatus, T. neglectus and Daphnella (Raphitoma) neozelanica and for the bivalve Marama (Hina) vaga Marwick, 1927. The fauna listed by Suter from GS 630 was for some years considered to be typical of Thomson's Waiarekan Stage. Marwick (1924b), however, showed that GS 630 was composite, wrongly attributed to T. Esdaile and wrongly localised. He concluded that the specimen of Struthiolaria frazeri Hutton identified by Suter was a stray, probably from the Nukumaruan of Ngarururoro, Hawke Bay, that some specimens of Limopsis recorded by Suter as L. aurita Brocchi were probably from Mount Harris, South Canterbury (i.e. Pareora Series), and the rest were probably from the Waihao Greensands at McCullough's Bridge.

The writer doubts that the bulk of the collection is, in fact, from the Tahu Member at McCullough's Bridge. The specimens concerned are better preserved than McCullough's Bridge shells, differ subtly in colour and are associated with a glauconitic, silty sandstone that is less glauconitic, finer-grained and lighter in colour than that from McCullough's Bridge.

A clue to the possible provenance of GS 630 is given by McKay (1887: 438) who notes that he collected fossils ("the same species as at Waikakahi Bridge", i.e. McCullough's Bridge) in greensands exposed at the mouth of what is now known as Pinnacle Gully about 2 km upstream from the bridge. No such collection is included

in his register of fossil localities, yet it seems unlikely that such an assiduous collector as McKay would have discarded the fossils collected on that occasion. Instead, it is more probable that the collection was temporarily mislaid and when rediscovered, incorrectly localised and attributed. McKay collected GS 642 from McCullough's Bridge on the same visit (June 1886) as he made the Pinnacle Gully collection, so if the latter is indeed GS 630, the closeness of the two numbers is explained.

In an attempt to check this theory, Dr Beu and the writer visited the presumed locality in October 1972 but were unable to discover any fossiliferous greensand exposed above river level, although underwater outcrops, apparently in glauconitic siltstone, could be seen in deep pools in the Waihao River. If this is in fact McKay's locality, then judging by exposures upstream, his collection came from within the Highcliff Siltstone, which would agree with the features of the matrix of GS 630 described above. Until such time as this locality can be collected, it is suggested that GS 630 be referred to as "Waihao R, possibly mouth of Pinnacle Gully".

4. GS 642 (given wrongly as 462 by Suter 1921: 63) "Waihao Bridge, 1½ miles below Waihao Forks McKay 1886" (from register). This is undoubtedly McCullough's Bridge and is the type locality of the following species of molluscs described by Suter (1917): Ostrea (Gigantostrea) mackayi, Ampullina waihaoensis, Exilia waihaoensis and Turris complicatus. A figured paratype of Surcula serotina Suter, 1917 (actually Marshallaria decipiens n.sp.) is also from here. The type of the first-named species is probably from the lower (Bortonian) part of the greensands but the others are almost

certainly from the Tahu Member.

2. TWENTIETH CENTURY COLLECTIONS

It would be tedious and not particularly valuable to discuss in detail the numerous collections that have been made from McCullough's Bridge this century. Two points should be made, however:

1. Collections made prior to Allan's revision of the stratigraphy of the Waihao Greensands may include fossils from below the "phosphatic band" (i.e. Bortonian) as well as from the overlying greensands.

2. Collections made prior to Srinivasan's revision of the type Tahuian may include material from the lower part (Bortonian) of the Ngapuke Member.

In fact, the majority (considerably more than 90%) of molluscs in the McCullough's Bridge collections examined by the writer are almost certainly from the Tahu Member. Very few appear to be from other lithological units at this locality.

A list of the important Geological Survey collections from the vicinity of McCullough's Bridge studied by the writer is given in Table 7.

Geological Survey Collection No. (GS ....)	N.Z. Fossil Record No. (S127/f...)	Collector(s)	Date of Collection	Locality	Grid reference (S127/.....) (1966 ed.)	Stratigraphic Unit	Stage
642	451	A. McKay	1886	"Waihao Bridge" (i.e.McCullough's Bridge)	550 024	Mostly from Tahu Member, but some from underlying units	Ak + Ab
1162	454	P. Marshall, J. Marwick, T.W. Vaughan	1923	Greensand below McCullough's Bridge	"	"	"
1986	552	D.A. Brown J. Marwick	1938	McCullough's Bridge, "upper bed above concretionary band"	"	Mostly from Tahu Member, probably some from Ngapuke Member	Ak + ?Ab
1987	456	"	"	McCullough's Bridge, "lower greensand ..... below concretionary band"	"	Lowest, unnamed unit	Ab
3272	477	H.W. Wellman	?1944	McCullough's Bridge "lowest bed exposed" (below cemented band)	"	"	"
3273	552	"	"	McCullough's Bridge, lower 20 ft (6.1 m) above cemented band	"	Mostly from Tahu Member, possibly some from Ngapuke Member	Ak + ?Ab
3274	478		"	McCullough's Bridge, 32 ft (10 m) above cemented band	"	Highcliff Siltstone Member	Ak
5643	552	C.A. Fleming, M. Gage, J. Marwick	1947	McCullough's Bridge "Type Tahuian" (i.e. above cemented band)	"	Mostly from Tahu Member, possibly some from Ngapuke Member	Ak + ?Ab
9480	801	P.A. Maxwell	1959-62	McCullough's Bridge above cemented band	"	Almost entirely from Tahu Member, possibly some from upper part of Ngapuke Member	Ak
9507	802	P.A. Maxwell, E. Esperitu	1965	McCullough's Bridge, lower 2 m above cemented band	"	Ngapuke Member (lower part)	Ab
9508	803	P.A. Maxwell et al.	1965-72	McCullough's Bridge, 4.5 - 6.5 m above cemented band	"	Tahu Member	Ak
11,449	854	P.A. Maxwell	1962-72	McCullough's Bridge, below cemented band	"	Lowest, unnamed unit	Ab
11,450	855	"	1968-72	McCullough's Bridge, 3 - 4.5 m above cemented band	"	Ngapuke Member (upper part)	Ak
11,200	856	P.A. Maxwell et al.	1968-72	Waihao R. at site of old ford and downstream for 200 m	535 027	Kapua Tuffs	Ak

Table 7. New Zealand Geological Survey Collections from McCullough's Bridge and Kapua Tuffs. Ab = Bortonian, Ak = Kaiatan.

CHAPTER VIII

SYSTEMATICS

INTRODUCTION

Classification

The classifications adopted in this study are, with some modifications that are primarily at the genus-group level, based on the following works:

Pelecypoda: Moore 1969 and 1971, except that the Malletiidae is merged with the Nuculanidae (see comments below).

Scaphopoda: Emerson 1962.

Gastropoda: Suprageneric classification follows that of Taylor and Sohl 1962, except that the Architectonicidae, Epitoniidae, Janthinidae, Triphoridae and Mathildidae are removed from the Mesogastropoda to the Heterogastropoda (Habe & Kosuge 1966) and the Canellariidae are transferred from the Neogastropoda to the Nematoglossa (Olsson 1970). Classification at the genus-group level is based partly on Moore 1960 and partly on Wenz (1938-1944) (Prosobranchia) and on Zilch (1959-60) (Euthyneura).

The following literature abbreviations are used in synonymies:

R.A.I.M. Records of the Auckland Institute and Museum.

B.A.I.M. Bulletin of the Auckland Institute and Museum.

N.Z.D.S.I.R. Bull. New Zealand Department of Scientific and Industrial Research, Bulletin.

N.Z.J.G.G. New Zealand Journal of Geology and Geophysics.

N.Z.G.S. Pal. Bull. New Zealand Geological Survey Paleontological Bulletin.

T.N.Z.I. Transactions of the New Zealand Institute.

T.R.S.N.Z. Transactions of the Royal Society of New Zealand.

J.R.S.N.Z. Journal of the Royal Society of New Zealand.

Man. N.Z. Moll. "Manual of the New Zealand Mollusca, with an Atlas of Quarto Plates". Government Printer, Wellington, 1913.

Cat. Tert. Moll. "Catalogue of the Tertiary Mollusca and Echinodermata of New Zealand in the collection of the Colonial Museum". Government Printer, Wellington, 1873.

Other abbreviations used in this chapter are:

Colln. Collection.

GS (preceding a number). New Zealand Geological Survey macrofossil collection.

TM (preceding a number). New Zealand Geological Survey Type Mollusca collection.

l.v. left valve (pelecypods).

r.v. right valve.

d.v. double-valved shell.

SYSTEMATICS

Phylum MOLLUSCA

Class PELECYPODA

Order NUCULOIDA

Superfamily NUCULACEA

Family NUCULIDAE

CLASSIFICATION OF NUCULIDAE

In the course of investigating the affinities of McCullough's Bridge nuculids, it became obvious that the previously described Cenozoic and Recent New Zealand species (33 in all) needed considerable revision at the supraspecific level. In particular, it seems that most of the species currently included in Nucula s.str. should be relocated in other taxa.

Most workers who have discussed the classification of the Nuculidae have made much of the presence or absence of internal marginal crenulations (see review in Schenck 1934). While this is generally a useful diagnostic feature, some anomalies do occur (e.g. in the genus Acila some species have distinctly crenulate margins, others have smooth margins - Schenck 1936: 15). A far more basic subdivision of the nuculids, based on shell structure, was proposed by Poel (1955), who subdivided the family into two major groups, one (typified by Nucula s.str.) in which the outer shell layer ("couche moyen" of Poel) is composed of numerous closely spaced radial elements, the other (including the Mesozoic genus Nuculoma) in which radial elements are entirely lacking. Shells in the former group usually, but not invariably, have surface radial sculpture corresponding to the

radial elements and many have well developed concentric sculpture as well. The inner shell margin is crenulated by the ventral extremities of the radial elements. Species belonging to the second group generally lack radial sculpture and internal crenulations, while concentric sculpture tends to be subdued. In addition, Sorgenfrei (1937, 1958) has pointed out that the small pits found on the dorsal surface near the hinge of some nuculids, occur only in those species lacking radial elements. These features are summarised in Table 8.

Poel concluded that the nuculids, with the exception of Acila, could be distributed among two genera, Nucula and Nuculoma, each with a number of subgenera. In the writer's opinion, this scheme is too conservative, leading to a number of disparate groups, with little in common apart from their shell structure, being included in the same genus. It is therefore proposed to recognise two subfamilies in the Nuculidae, the Nuculinae and Nuculominae (nov.), distinguished primarily by their shell structure. Many of the taxa accepted as subgenera of Nucula or Nuculoma by Poel are probably worthy of full generic rank. Acila, excluded from Poel's discussion, lacks radial elements (Schenck 1936: 21) and is therefore included in the Nuculominae, although its strong divaricate sculpture sets it well apart from other members of the subfamily. The classification adopted here is given below.

Subfamily Nuculinae

Genus Nucula Lamarck, 1799

Subgenus Nucula s.str.

" Varionucula nov.

" Lamellinucula Schenck, 1944

Genus Pectinucula Quenstedt, 1930

Shell feature	Nuculinae	Nuculominae
Subsurface radial elements	Always present	Always absent
Surface radial sculpture	Usually present	Rarely present (*Mauinucula*)
Surface concentric sculpture	Usually present	Usually weakly developed
Internal marginal crenulations	Always present	Present only in *Acila*
Dorsal pits	Absent	Sometimes present

Table 8. Comparison of shell features in Nuculinae and Nuculominae.

Genus Linucula Marwick, 1931

Genus Gibbonucula Eames, 1951

Genus Pronucula Hedley, 1902

Genus Nanonucula nov.

?Genus Nuculoidea Williams and Breger, 1916

Subfamily Nuculominae nov.

Genus Nuculoma Cossmann, 1907

Genus Nuculopsis Girty, 1911

Subgenus Nuculopsis s.str.

" Palaeonucula Quenstedt, 1930

Genus Leionucula Quenstedt, 1930

Genus "Nuculopsis" Woodring, 1925 (not of Girty, 1911)

Genus Ennucula Iredale, 1931

Genus Zenucula nov.

Genus Mauinucula nov.

Genus Austronucula Powell, 1939

Genus Brevinucula Thiele, 1934

Genus Trigonucula Ichikawa, 1949

Genus Acila H. and A. Adams

Subgenus Acila s.str.

" Truncacila Schenck, 1931

Besides the four groups proposed herein, three of the genus-group taxa listed above were not discussed by Poel, viz. Austronucula, Trigonucula and Nuculoidea. The type species of Austronucula lacks radial elements and is here referred to the Nuculominae (but see discussion below). Trigonucula lacks radial sculpture and ventral crenulations (Ichikawa 1949: 267-8) and seems confidently placed in the same subfamily. Nuculoidea was proposed by Williams and Breger (1916: 173) for certain Lower Paleozoic nuculids with "a

nonpectinated ventral margin", which would qualify it for inclusion in the Nuculominae; however, Keen (in Moore 1969: N231) describes the ventral margin as "microscopically crenate" which suggests that Nuculoidea is an early member of the Nuculinae.

Poel also included Deminucula Iredale, 1931 in his classification of the Nuculidae, treating it as a subgenus of Nuculoma. Schenck (1934: 43-4), however, noted that the type species (D. praetenta Iredale) lacks a resilifer, which casts doubt on its supposed nuculid affinities. McAlester (in Moore 1969: N234) treats Deminucula as a subgenus of the "malletiid" taxon Tindaria.

CLASSIFICATION OF NEW ZEALAND NUCULIDAE

Dell (1956b: 12) distributed the 15 living New Zealand nuculids among five genera, assigning six species to Nucula s.str. and the others to Ennucula (one species), Linucula (two species), Pronucula (four species) and Austronucula (two species). Powell (1957: 75, 1962: 116) followed Dell's classification, but treated Ennucula as a subgenus of Nucula. Powell (1971: 227) has subsequently described an additional Recent species of Nucula s.str.

Fleming's checklist of Cenozoic molluscs (1966: 16) lists 21 species of nuculids (several of which are also known living), distributed among four genera, viz. Nucula (with 11 species), Ennucula (two species), Linucula (six species) and Pronucula (two species). No fossil species of Austronucula have been described.

The writer's work indicates that the above classifications require extensive revision; in particular, it seems that most of the species referred to Nucula s.str. require relocation in other taxa. These are discussed in the following notes.

Genus Nucula s.l.

The type species of Nucula, N. nucleus (Linnaeus), has a moderately large shell (length up to about 12 mm), of ovate outline with fine radial sculpture and weak concentric striae. Internal crenulations are confined to the ventral margin and correspond to the (largely subsurface) radial elements. The chondrophore projects strongly, roughly bisecting the angle between the anterior and posterior series of teeth. Of the described New Zealand nuculids, only N. nitidula A. Adams compares closely with N. nucleus in features of sculpture and marginal crenulations. N. nitidula has an anteriorly oblique chondrophore, partially fused to the ventral margin of the anterior series of teeth, rather than projecting freely as in N. nucleus. This difference may warrant subgeneric separation from Nucula nucleus when more is known of hinge details in the genus but for the time being N. nitidula is included in Nucula s.str.

Schenck (1944) proposed Lamellinucula (as a subgenus of Nucula) for species with crenulate margins like Nucula s.str. but having "incised, lamellate concentric sculpture more conspicuous than radial ribs or striae". The type species, Nucula tamatavica Odhner, has the chondrophore almost horizontal and fused to the ventral margin of the anterior hinge. Schenck included Nucula ambrosia Bartrum and Powell, N. dunedinensis Finlay, N. hartvigiana Dohrn and N. sagittata Suter in his sub-genus, but his paper has either been overlooked or ignored by New Zealand workers, and Lamellinucula does not appear in the above-mentioned checklists. Of the above species only Nucula ambrosia seems closely related to N. tamatavica, agreeing with it in sculptural and hinge features, whereas the super-

ficially similar N. hartvigiana belongs in Linucula (see below). Nucula sagittata is here referred to the new subgenus Varionucula described below. Nucula dunedinensis has prominent concentric sculpture but is much smaller than N. tamatavica and has a considerably less oblique chondrophore than projects freely from the hinge. Nonetheless, it is provisionally included in Lamellinucula along with Nucula rossiana Finlay and N. vestigia Marwick, although all differ to some degree from N. tamatavica. Nucula vestigia, in particular, has unusual sculpture consisting of irregularly divaricate ridges and fine radial costellae, quite unlike that found in any other nuculid known to the writer. When more is known of the fossil New Zealand nuculids it may be necessary to propose new taxa for these species, but in the meantime it seems wiser to retain them in Lamellinucula, if only to emphasise that they differ markedly from Nucula nucleus. It may be noted that Glibert and Poel (1965: 15) have suggested that Lamellinucula is polyphyletic and not a natural group, as presently conceived.

Subgenus Varionucula nov.

Type species: Nucula gallinacea Finlay, 1930, Recent, New Zealand.

Shell moderately large for genus (up to 15 mm in length), ovate, usually moderately inflated, posterior end subangled, anterior end well-rounded. Lunule and escutcheon well-defined. Concentric sculpture prominent, consisting of narrow rounded or flat-topped ridges with a tendency to anastomose on posterior portion of disc and at edge of lunule, well-spaced on earliest known species, but closely-spaced on younger species. Radial sculpture on disc of fine costellae that tend to surmount the concentric ridges. Escutcheon

and lunule with much more obscure radial sculpture, largely subsurface in position. Lunule with short thickened ridges oblique to both concentric and radial sculptural elements, rather irregular in N. sagittata but quite regular in the type species and in N. crepida. No analagous sculpture on escutcheon. Hinge rather narrow in type species, quite heavy in N. sagittata, type species with 19 and 9 posterior teeth. Chondrophore strongly oblique, directed anteriorly, upper edge fused to ventral margin of anterior hinge plate. External ligament groove long and very narrow, extending forwards from beak for about one third length of anterior hinge plate. Ventral margin finely crenulate, dorsal margins smooth except for very fine crenulations near distal end in some specimens.

Dell (1956a: 28-30, figs. 11-13) redescribed and figured the type species (originally described from young shells) and referred it to Linucula Marwick on the basis of the oblique ridges on the lunule ("escutcheon" in Dell's description). These ridges, however, are not analogous to the divergent elements (basically subsurface) on both lunule and escutcheon of Linucula (see discussion below) but have evolved independently within Nucula s.l.

The new subgenus differs from Lamellinucula s.str. in its narrower concentric ridges, rather more prominent radial sculpture, and in the presence of oblique sculptural elements on the lunule. Besides the type species, Varionucula includes Nucula sagittata and N. crepida Marwick and the new species described below. Further undescribed species are known from the mid-Cenozoic of New Zealand. The stratigraphic range is Kaiatan (or Bortonian) to Recent.

Genus Linucula Marwick

Marwick (1931: 49) proposed Linucula (as a subgenus of Nucula) for species having "sculpture of numerous weak radials; lunule and escutcheon with much finer divaricate radials". Schenck (1934: 26) noted the distinctive features of Linucula and concluded that it "should not be classed as a subgenus of Nucula" and that acquisition of more material "may prove it merits recognition as a genus". Nonetheless, Schenck in his summary of taxonomic groups in the Nuculidae included Linucula as a subgenus of Nucula (1934: 46). Dell (1956a: 27-8) formally elevated Linucula to full generic rank and in a later paper (1964: 143-4) outlined its diagnostic features and recorded it outside the New Zealand region for the first time. Keen (in Moore 1969: N231), however, relegated Linucula to subgeneric rank under Nucula.

The presence of divergent sculpture on the dorsal areas of Linucula is not as important and fundamental as the nature of the subsurface structure in this region; as noted above, oblique ridges are present on the lunule of species of Varionucula, here interpreted as a subgenus of Nucula. In Nucula, Lamellinucula and Varionucula, the radial elements comprising the outer shell layer extend across the disc but not (except in a few cases) onto the narrow areas adjacent to the dorsal margins (usually referred to as lunule and escutcheon). Marginal crenulations (which mark the distal extremities of the radial elements) are therefore normally confined to the ventral margin, though in a few cases /e.g. in Nucula (Varionucula) gallinacea/ they may extend a short distance onto the lower part of the dorsal margins. In Linucula, the dorsal areas are constructed of bunches of fine subsurface elements which diverge

obliquely from the radial elements, swinging around to become normal to the shell margins. The fine crenulations marking the distal extremities of these elements extend around the dorsal margins almost to the beak, and in well-preserved shells are the quickest way of recognising the genus. These dorsal crenulations are sharply marked off by their smaller size from the ventral crenulations.

About one third of the named New Zealand nuculids have the shell-structure described above and are therefore included in Linucula. As such, the genus includes species which exhibit considerable variety in shell-form, sculpture and hinge features. A few species, including L. ruatakiensis, L. waipaoa and L. tutamoensis have relatively small, rounded shells in which the radial elements have virtually no surface expression and concentric sculpture is faint or absent. The hinges of these species are light and broadly arched and bear a small, scarcely projecting chondrophore. The common living species L. hartvigiana, on the other hand, grows to twice the dimensions of L. ruatakiensis, has an ovate shell with prominent concentric sculpture and a strong, obtusely angled hinge with a prominently projecting chondrophore. Linucula wanganuica is similar but has much weaker concentric sculpture. When more is known of the fossil forms it may prove desirable to separate some species subgenerically or even generically from L. ruatakiensis; however, for the time being they are all retained in Linucula.

Linucula has a known range of Duntroonian to Recent in New Zealand. Dell (1964: 144) has recorded the genus from "South Africa, the west and east coasts of North, Central and South America, northern Europe and the Mediterranean" (apparently all Recent occurrences).

Genus Pronucula Hedley

Australasian workers have used Pronucula for virtually all small nuculids (length less than 3 mm) with prominent prodissoconchs and some sort of radial sculpture. However, as noted by Dell (1956b: 11) for the Recent New Zealand species, it is very doubtful if all the species so assigned are truly congeneric with P. decorosa, the type species. Pronucula decorosa has prominent radial sculpture and a broadly arched hinge in which the teeth are distinctly separated from the small, vertical chondrophore. Among the described New Zealand species, only P. tenuis has strong radial sculpture, very fine concentric sculpture and a hinge like P. decorosa; the others, particularly P. bollonsi and P. maoria, differ significantly from the type species (see Dell 1956b: 11). Nucula ngatutura [referred to Pronucula by Laws (1940: 429)] has a hinge not unlike P. decorosa but the radial sculpture is weak and overshadowed by the prominent concentric sculpture. Nonetheless, the hinge features are probably more significant than the external sculpture and ngatutura is therefore treated here as a species of Pronucula. Pronucula maoria and P. totangiensis are tentatively referred to the new genus described below, while P. bollonsi [the type of which may not be adult as suggested by Dell (1956b: 11)] must remain of uncertain classification.

Genus Nanonucula nov.

Type species: Nanonucula insolita nov.

Nanonucula is proposed for very small but rather robust nuculids of subelliptical to subtrigonal outline, prominent prodissoconch and a comparatively heavy hinge bearing a small chondrophore that does not project below the base of the hinge-plate. The teeth are not separated from the chondrophore as in Pronucula, but

extend right up to it. The surface radial sculpture in the type species and in a related form from the Otaian of Parengarenga Harbour is extremely faint, but the subsurface radial elements show clearly through the shell. (These elements are effectively obscured by the gold-palladium coating in SEM photographs). Concentric sculpture in the above two species consists of weak growth lines, but the Recent New South Wales Pronucula voorwindei Bergmans, 1969, which has the solid shell and hinge-features of the new genus, has strong concentric ribs and fine but distinct radial costellae. Rather similar sculpture is present on the living New Zealand species Nucula certisina which has similar hinge features to Nanonucula insolita and is tentatively considered congeneric. Pronucula maoria is also a possible congener of N. insolita; it has a somewhat similar hinge /though Powell's figure (1937: Pl. 45, fig. 8) shows a rather larger, slightly projecting chondrophore/ and similar sculpture, but the shell is described as "very thin, fragile" (Powell 1937: 163) which does not accord well with the rather solid, thickened shell of Nanonucula insolita.

Genus Ennucula Iredale

Iredale (1931: 202) distinguished his genus from Nucula on the basis of its strongly oblique chondrophore, scarcely angled hinge and smooth ventral margin. These features have been considered sufficient to warrant recognition of Ennucula as a full genus (e.g. by Dell 1956b: 11, 1964: 139; Soot-Ryen 1959: 12), but other authors have classed it as a subgenus of Nucula (Schenck 1934: 46) or of Nuculoma (Poel 1955) or as a synonym of Leionucula (Keen in Moore 1969: N231). The lack of radial elements puts Ennucula in the

Nuculominae along with both Nuculoma and Leionucula, but it seems different enough from the former to justify generic separation. The type species of Nuculoma, Nucula castor d'Orbigny is a Jurassic form with a very prominent rounded umbo situated near the posterior end of the shell and quite prominent concentric sculpture. These features suggest only remote relationship to Ennucula. Leionucula is based on a rather rare Cretaceous species Nucula albensis, which is not unlike some species of Ennucula in general shape except for its rather more prominent lunule and escutcheon, but has stronger concentric growth lines than Ennucula. The hinge of L. albensis has not been figured but Schenck (1934: 34, footnote) describes it as arched, with about 25 anterior and 10 posterior teeth and an oblique chondrophore. Unfortunately this description is insufficiently detailed to allow comparison with the hinge in Ennucula in which the chondrophore is strongly oblique, often almost horizontal, with its upper edge fused to the lower part of the anterior hinge plate. Consequently, it is not possible at this stage to decide whether Ennucula is indeed a synonym of Leionucula or worthy of sub-generic separation. It is provisionally treated as a full genus of world-wide distribution.

Genus Zenucula nov.

Type species: Nucula strangeiformis Dell, 1956, Recent, New Zealand.

Zenucula is proposed for nuculomines differing from Ennucula in their smaller size, greater inflation, less elongate, more rounded outline and in having a smaller, scarcely projecting and almost vertical or only slightly oblique chondrophore. Dell (1956b: 9) noted that the disposition of the chondrophore in strangeiformis suggests closer relationship to Nucula s.l. than to Ennucula, but

that the lack of marginal crenulations is anomalous. The shell structure is considered more important for elucidating gross relationships in the Nuculidae, and Zenucula is therefore included in the Nuculominae. Besides the type species, Zenucula includes Nucula grangei (Tongaporutuan), which differs in being more rotund and more equilateral.

Genus Mauinucula nov.

Type species: Nucula otamaringaensis Marwick, 1926, Upper Miocene, New Zealand.

Shell ovate, robust, moderately inflated, attaining a comparatively large size (at least 30 mm in length). Concentric sculpture of low, narrow and rather irregular ribs with some intercalation near edges of disc, tending to become subdued distally and stopping abruptly at edges of lunule and escutcheon. Radial sculpture on surface only, no subsurface radial elements, consisting of numerous narrow costellae which are most prominent at edges of disc, broader but more subdued in central part. Hinge poorly known (not seen in type species), apparently quite strong and broadly arched as in Ennucula but with a heavy, strongly projecting and oblique chondrophore that is set well below the rest of the hinge-plate.

The affinities of this taxon are uncertain; the presence of definite radial sculpture (as distinct from microscopic striae) sets it apart from other taxa in the Nuculominae but the general style of the hinge, apart from the deeply sunken chondrophore, is reminiscent of Ennucula. "Nuculopsis Woodring, 1925" (not of Girty, 1911) (type species, Nucula (Nuculopsis) hilli Woodring, 1925, Miocene, Jamaica) may be related, but the type species is much smaller than

Mauinucula otamaringaensis (length only 8.9 mm) and lacks radial sculpture.

Besides the type species, Mauinucula includes undescribed species from Cape Foulwind (Runangan) and from the Bluecliffs Siltstone of Bluecliffs and Pareoa R. (Otaian). The latter species is not uncommon at the two localities mentioned but is extremely difficult to collect in a satisfactory condition. The description of the hinge given above is based on a fragmentary specimen from Bluecliffs. Nucula waikuraensis is very doubtfully referred to Mauinucula; the holotype (the only known specimen) has somewhat similar, though rather coarser, concentric sculpture to otamaringaensis but seems to lack radial sculpture entirely. The interior of the shell is unfortunately obscured by matrix and it is possible that this species is not even a nuculid.

The known local stratigraphic range of Mauinucula is Runangan to Opoitian.

Genus Brevinucula Schenck, 1934

The type species of this genus has a small, triangular shell with a length : height ratio of about 1, lacking subsurface radial elements and any surface sculpture apart from weak growth lines. The hinge is acutely angled with a small, vertical, scarcely projecting chondrophore. The adductor muscle scars are more distinctly impressed than is usual in the nuculids. (See Knudsen 1970: 19-21). The only New Zealand occurrence of the genus known to the writer is in the Otaian of Parengarenga Harbour.

Genus Austronucula Powell

Powell (1939: 220) proposed Austronucula for a Stewart Island species that "conforms in hinge details with Pronucula Hedley .... but differs in having a smooth ventral margin .... and a more conspicuously marked off prodissoconch". A second New Zealand species, A. galatheae, was described by Dell (1956a: 30). Both species are very small, A. schencki measuring only 1.15 x 1 mm and A. galatheae 2.18 x 1.68 mm. Powell suggested that Nucula micans Angas and possibly Pronucula flindersi Cotton (both Recent south-east Australian species) should be referred to Austronucula. Another Australian species that may belong to Austronucula is Nucula pusilla Angas.

Austronucula lacks radial elements and is therefore referred to the Nuculominae; however, it is quite possible that the species included in the genus have arisen neotenously from several different nuculine forms. Prodissoconchs in Nucula s.l. and Linucula lack radial elements and it is not difficult to envisage nuculine species giving rise to Austronucula-like shells by suppression of the "adult" shell-structure.

The classification of New Zealand Cenozoic and Recent nuculids is summarised below (age of holotype given after name).

Subfamily NUCULINAE

Genus Nucula Lamarck

1799 Mem. Soc. hist. nat. Paris: 87.

Type species (by monotypy): Arca nucleus Linnaeus, 1758. Recent, Europe.

Nucula (Nucula) nitidula A. Adams, 1856 (= N. castanea A. Adams, 1856). Recent.

Subgenus Lamellinucula Schenck

1944 J. Paleont. 18(1): 97-8.

Type species (original designation): Nucula tamatavica Odhner, 1943 (new name for N. rugosa Odhner, 1919, preoccupied). Recent, Madagascar.

Nucula (Lamellinucula) ambrosia Bartrum and Powell, 1928. Opoitian.

? N. (Lamellinucula) dunedinensis Finlay, 1928. Recent.

? N. (Lamellinucula) rossiana Finlay, 1930. Recent.

? N. (Lamellinucula) vestigia Marwick, 1929. Duntroonian.

Subgenus Varionucula nov.

Type species: Nucula gallinacea Finlay, 1930. Recent, New Zealand.

Nucula (Varionucula) gallinacea Finlay, 1930. Recent.

N. (Varionucula) sagittata Suter, 1917. Altonian.

N. (Varionucula) crepida Marwick, 1931. Clifdenian.

N. (Varionucula) kohika n.sp. Bortonian or Kaiatan.

Genus Linucula Marwick

1931 N.Z. Geol. Surv. Paleont. Bull. 13: 49.

Type species (original designation): Nucula ruatakiensis Marwick, 1926, Upper Miocene, New Zealand.

Linucula ruatakiensis (Marwick, 1931). Tongaporutuan.

L. hartvigiana (Dohrn, 1864). Recent.

L. recens Dell, 1956. Recent.

L. nitidulaformis (Powell, 1971). Recent.

L. wanganuica Laws, 1940. Nukumaruan.

L. aptera Laws, 1940. Mangapanian.

L. tutamoensis (Marwick, 1931). Lillburnian.

L. waipaoa (Marwick, 1931). Altonian.

L. waiotea Laws, 1941. Altonian.

L. otamatea (Laws, 1939). Otaian.

L. tersior (Marwick, 1929). Duntroonian.

Genus Pronucula Hedley

1902 Mem. Austral. Mus. 4(5): 290.

Type species (original designation): Pronucula decorosa Hedley, 1902, Recent, south-east Australia.

Pronucula tenuis Powell, 1927. Recent.

P. ngatutura (Laws, 1936). Opoitian.

Genus Nanonucula nov.

Type species: Nanonucula insolita n.sp., Upper Eocene, New Zealand.

Nanonucula insolita n.sp. Kaiatan.

? N. maoria (Powell, 1937). Recent.

? N. certisinus (Finlay, 1930). Recent.

? N. totangiensis (Marwick, 1931). Altonian.

Nuculinae incertae sedis

Pronucula bollonsi Powell, 1955. Recent.

Subfamily NUCULOMINAE

Genus *Ennucula* Iredale

1931 Rec. Austral. Mus. 18(4): 202.

Type species (original designation): *Nucula obliqua* Lamarck, 1819. Recent, south-east Australia.

Ennucula strangei (A. Adams, 1856). Recent.

E. whatu n.sp. Kaiatan.

Genus *Zenucula* nov.

Type species: *Nucula strangeiformis* Dell, 1956. Recent, New Zealand.

Zenucula strangeiformis (Dell, 1956). Recent.

Z. grangei (Marwick, 1926). Tongaporutuan.

Genus *Mauinucula* nov.

Type species: *Nucula otamaringaensis* Marwick, 1926. Upper Miocene, New Zealand.

Mauinucula otamaringaensis (Marwick, 1926). Tongaporutuan.

M. waikuraensis (Marwick, 1931). Lillburnian.

Genus *Austronucula* Powell

1939 Rec. Auck. Inst. Mus. 2(4): 220.

Type species (original designation): *Austronucula schencki* Powell, 1939. Recent, New Zealand.

Austronucula schencki Powell, 1939. Recent.

A. galatheae Dell, 1956. Recent.

Genus Brevinucula Schenck

1934. Bull. Mus. roy. Hist. nat. Belg. 10(20): 40.

Type species (original designation): Nucula guineensis Thiele, 1931 (= Nucula verrilli Dall, 1886, nom. nov. pro N. trigona Verrill, 1885, preoccupied). Recent, Atlantic

Synonym (objective): Brevinucula Thiele

1935 Handb. Syst. Weichtierkunde 2: 786.

Brevinucula n.sp. Otaian.

Subfamily NUCULINAE

Genus Nucula Lamarck

Subgenus Varionucula nov.

Nucula (Varionucula) kohika n.sp. Pl. 1, fig. 10.

ETYMOLOGY: From the Maori kohika - ancestor.

DESCRIPTION: Shell rather small, elongate-ovate, moderately inflated, beak at posterior seven tenths. Anterodorsal margin gently convex, anterior end truncated, sloping forwards at about 30° to vertical. Posterodorsal margin incomplete but apparently gently convex or obtusely angled; posterior end narrowly rounded, ventral margin broadly and evenly convex. Lunule long and narrow, separated from broad anterior area by an ill defined ridge. Posterior area long and narrow, separated from disc by break in slope. Escutcheon missing. Area around beak corroded, concentric sculpture on rest of disc consisting of low, narrow, rather sharp ridges of rather irregular spacing but with interspaces always considerably wider than the ridges. These concentrics tend to anastomose on the posterior portion of the disc and become subobsolete on the posterior area. They persist across the anterior area, stopping at the edge

of the lunule where a few ill-defined, irregular nodules are present, having no obvious relationship to the concentric sculpture. Radial sculpture consisting of about 60-70 fine threads, well-spaced anteriorly but more crowded on posterior part of shell. Hinge damaged near beak, at least 10 anterior and 4 posterior teeth remaining. Ventral margin finely crenulate within.

DIMENSIONS OF HOLOTYPE (l.v.): Length 7.2, height 5.6, inflation (1 valve) 1.9 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 1986, McCullough's Bridge (Bortonian or Kaiatan - possibly from the lower part of Ngapuke Member, judging by preservation, i.e. Bortonian).

REMARKS: Although the only specimen has the hinge badly damaged, the shape and sculptural features of this species suggest that it is an early member of the Nucula sagittata-gallinacea group. Chief differences are the wider spacing of the concentric ridges, finer radial sculpture and the weaker, rather ill-defined oblique ridges on the lunular area.

Genus Nanonucula nov.

Nanonucula insolita n.sp. Pl. 16, figs. 210, 211.

DESCRIPTION: Shell very small, subelliptical, rather robust due to internal thickening of shell on dorsal half of disc. Beak prominent, rounded, at posterior three fifths; prodissoconch large, smooth. Anterior and ventral margins evenly rounded, posterior end obliquely and weakly truncated. Radial elements almost entirely sub-surface, consisting of about 60 costellae. Concentric sculpture of weak

growth lines. Hinge plate assymetrical, gently arched; anterior series with 7, posterior series with 4 small teeth, separated by tiny, non-projecting resilifer. Inner ventral margin finely crenulate.

DIMENSIONS OF HOLOTYPE (r.v.): Length 1.9 mm, height 1.7 mm, inflation 0.55 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (Kaiatan).

LOCALITIES: GS 9480 (holotype); GS 9508, Tahu Member, McCullough's Bridge (one paratype).

REMARKS: Nanonucula insolita differs from other described New Zealand nuculids in its combination of small size, robust shell, almost complete absence of surface sculpture and in hinge details, especially the small resilifer which does not project ventrally.

Subfamily NUCULOMINAE

Genus Ennucula Iredale

Ennucula whatu n.sp. Pl. 1, figs. 1, 2.

ETYMOLOGY: From the Maori whatu - stone or kernel of fruit.

DESCRIPTION: Shell small, ovate, fragile, not greatly inflated, beak small, at posterior two thirds. Anterodorsal margin lightly convex, merging smoothly with well-rounded anterior end; posterodorsal margin short, gently convex above hinge, almost straight behind, junction with the broadly convex ventral margin subangled. No definite lunule observed but a rather broad, slightly depressed anterior area. Posterior area semilunular, impressed. Exterior

smooth apart from very weak concentric growth lines and occasional stepped ridges. Hinge long and narrow, broadly arched; anterior series with about 19 teeth, the proximal 5 or 6 small and tubercular, remainder tall and narrowly triangular, some with weakly chevron-shaped bases. Posterior series much shorter with 8 chevron-based teeth, all of rather similar size, separated from anterior series by a deeply recessed, narrow chondrophore, projecting strongly below hinge and directed forwards at about 40° to the vertical. Ligament groove very narrow, almost horizontal, extending along dorsal margin from beak to the 7th tooth in anterior series. Inner margins smooth, adductor muscle scars obscure.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (r.v.)	9.0	6.5	1.8
Paratype (l.v.) (GS 9480)	6.2	4.5	1.4

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

LOCALITIES: GS 9508 (holotype and one paratype - see below; also odd fragments); GS 9480, McCullough's Bridge (paratype); GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (two double-valved shells probably belonging here - see below).

REMARKS: The above description is based on the well-preserved holotype and the paratype from GS 9480. The shells from the Kapua Tuffs are double-valved specimens that differ from the types in their less elongate shape (9.2 x 7.1 and 7.7 x 5.7 mm), more strongly arched anterodorsal margin, rather more prominent posterior area and stronger growth lines. These specimens might well be regarded as belonging to a separate species but for the fact that a left valve has been

collected from GS 9508 that resembles them in shape (it measures 9.0 x 7.4 mm) and the convexity of the anterodorsal margin. The growth lines are about as strong as those on the holotype of E. whatu; the hinge is more strongly arched though otherwise similar (except that, as far as can be judged, there are fewer anterior teeth - about 16 instead of 19). The hinges of the Kapua shells have not been seen and rather than postulate the existence of two species at McCullough's Bridge, one of which persists into the Kapua Tuffs, it seems wiser to include all specimens in E. whatu, at least until considerably more material is available from both localities. It may be noted that the living species E. strangei shows variation in shape similar to that described above.

Ennucula whatu is very similar to E. strangei in features of shape and sculpture, but has a heavier hinge bearing more numerous teeth (13-15 anterior and six posterior teeth in E. strangei of comparable size). Recent specimens of E. strangei have a thin, golden-brown epidermis and it is interesting to note that a very similar layer is present on the smaller of the specimens from the Kapua Tuffs.

Superfamily NUCULANACEA

Family NUCULANIDAE

Genus *Saccella* Woodring

1925 Carnegie Instn. Wash. Publ. 366: 15.

Nom. subst. pro *Ledina* Sacco, 1898 non *Ledina* Dall, 1898.

Type species (original designation): *Arca fragilis* Chemnitz, 1784.

Recent, Mediterranean.

Saccella semiteres (Hutton, 1877)

1877 *Leda semiteres* Hutton; T.N.Z.I. 9: 598.

1915 *Leda semiteres*; Suter, N.Z.G.S. Pal. Bull. 3: 47, pl. 8, fig. 18.

1926 *Nuculana belluloides* Allan; T.N.Z.I. 56: 344-5, pl. 77, figs. 9a, b.

1926 *Nuculana semiteres* (= *N. belluloides*); Allan, T.N.Z.I. 57: 291 (footnote).

1927 *Nuculana (Saccella) semiteres* (= *N. belluloides*); Finlay, T.N.Z.I. 57: 445.

1950 *Nuculana (Saccella) semiteres*; Fleming, T.R.S.N.Z. 78 (2-3): 240.

1966 *Saccella semiteres*; Fleming, N.Z. D.S.I.R. Bull. 173: 16.

DESCRIPTION: Shell small, inflated, elongate-ovate, rostrate, beaks fairly prominent, slightly opisthogyrous, set at about anterior two-thirds to three-fifths. Anterodorsal margin lightly convex, merging smoothly with well-rounded anterior end. Posterodorsal margin long, almost straight, often with a weak hump about two thirds distance from beak. Posterior end narrow and rounded, ventral margin broadly convex, becoming only slightly flattened on approaching the posterior

end. Posterior area well-defined, bounded by a narrow, rounded ridge running from the beak to the posterior end. Within the posterior area is a much more weakly defined ridge running from the beak to the hump on the posterodorsal margin, dividing the area into two gently concave parts. No lunule. Concentric sculpture of narrow, rounded costae of irregular spacing, even within an individual, interspaces sometimes narrower, sometimes much wider than costae. About 5-7 costae/mm on distal half of adult shells. Some costae appear to be interstitial in nature, not persisting beyond the disc onto the dorsal parts of the shell. In most shells the costae cross the umbonal ridge unchanged but die out rapidly on reaching the inner ridge of the posterior area, so leaving a smooth inner zone. In a few specimens there is also a fairly broad smooth area immediately in front of the umbonal ridge, although the costae are still prominent on the outer zone of the posterior area. Hinge long, narrow, assymetrical, angled below beak, anterior series with up to 16, posterior series with up to 17 chevron-based teeth (anterior teeth normally slightly more numerous), separated by a well-recessed resilifer. Anterior adductor muscle scar of moderate size, reniform, posterior scar much smaller, elongate-ovate. Pallial sinus shallow, rounded.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype L. semiteres (fide Suter 1915)	12	7	5 (2 valves)
Holotype N. belluloides (fide Allan 1926)	10	5	3 (2 valves)

HOLOTYPE: L. semiteres; Otago Museum, Dunedin.

N. belluloides; Canterbury Museum.

TYPE LOCALITY: L. semiteres; "Waiho" (sic) - probably McCullough's

Bridge (see section on collections).

N. belluloides; McCullough's Bridge.

LOCALITIES: McCullough's Bridge (generally well-represented in all collections from Tahu Member); GS 9507, lower 2 m of Ngapuke Member, McCullough's Bridge (Bortonian); left bank Waihao River opposite Waihao Downs (Bortonian); Pahi Greensands, Kaipara Harbour, Northland (Bortonian) (Fleming 1950: 240).

Olson (in Gage 1957: 121) recorded Nuculana (Saccella) semiteres from Target Gully, Oamaru (Altonian) but specimens of Saccella from this and other North Otago Altonian localities (e.g. Ardgowan) differ from McCullough's Bridge shells in having distinctly concave posterodorsal margins and broader but lower concentric costae which tend to become obsolete at the umbonal ridge more readily than in S. semiteres.

STRATIGRAPHIC RANGE: Bortonian-Kaiatan.

REMARKS: Saccella semiteres is an early member of a rather compact group of nuculanids that ranges throughout much of the New Zealand Cenozoic up to the present day, and includes such species as S. probellula (Marwick, 1929) (Duntroonian), S. arowhana (Marwick, 1931) (Otaian-Clifdenian), S. redunca (Dell, 1950) (Otaian) (probably a synonym of arowhana), S. tenellula (Bartrum and Powell, 1928) (Opoitian), S. waihiana (Powell, 1931) (Waipipian) and S. bellula (A. Adams, 1856) (Nukumaruan-Recent). Saccella bellula lives in depths of 8-280 m (Dell 1956b: 164); the fossil species appear to have been typically shelf-dwelling but also to have ranged into deeper waters. Another, quite distinct group with a comparable stratigraphic range, seems to have been more typical of deeper waters, though species representing both groups occur in shallow-water sediments at Pahi,

Northland (Fleming 1950). Members of this group include S. pahiensis (Fleming, 1950) (Bortonian), S. waikohuensis (Marwick, 1931) (Tongaporutuan), S. onairoensis (Marwick, 1931) (Tongaporutuan-Kapitean), S. falcigera Marwick, 1965 (Opoitian), S. webbi Marwick, 1965 (Nukumaruan) and S. hedleyi Fleming, 1951 (Recent). The distinctiveness of this group has also been recognised by Marwick (1965: 16).

Saccella semiteres differs from S. probellula in having somewhat coarser and less regular concentric sculpture and a less sharply defined umbonal ridge. The Recent S. bellula is distinguished from the Eocene species by its narrower posterior end, by the tendency for the concentric costae to bifurcate on crossing the umbonal ridge, and by the serrated profile of the umbones, caused by the elevation of the costae into sharp ridges on the umbonal margins.

Genus Jupiteria Bellardi

1875 Monogr. Nuculidi Terr. terz. Piemonte e Liguria: 20.
Type species (subsequent designation, Dall, 1898): Nucula concava Bronn, 1831, Pliocene, Italy.

Jupiteria sp.

Three small specimens, the largest measuring 3.7 x 2.8 mm, are a species of Jupiteria, possibly conspecific with J. hampdenensis (Marwick, 1942) (Bortonian, Hampden) but their small size precludes direct comparison with the holotype. They are characterised by their rounded-trigonal shape, inflated shell, almost straight, steeply descending posterodorsal margin and sculpture of fine concentric grooves which are largely confined to the distal part of the shell and obsolete on posterior area.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Genus Pseudoportlandia Woodring

1925 Carnegie Inst. Wash. Publ. 366: 20.

Type species (original designation): Leda clara Guppy, 1873, Miocene, Jamaica.

Pseudoportlandia tahuia (Marwick, 1942)

1926 Nuculana solenelloides (Marshall); Allan, T.N.Z.I. 56: 344 (not Sarepta solenelloides Marshall, 1919).

1926 Nuculana solenelloides (Marshall); Allan, T.N.Z.I. 57: 291 (not of Marshall).

1942 Nuculana (Pseudoportlandia) tahuia Marwick; T.R.S.N.Z. 72(3): 268, pl. 23, figs. 1, 2.

1966 Pseudoportlandia tahuia; Fleming, N.Z. D.S.I.R. Bull. 173: 17, pl. 4, figs. 72, 73.

DESCRIPTION: Shell small, robust, inflated, elliptical, almost equilateral; beaks opisthogyrous, sub-central. Anterodorsal margin gently convex, descending rather slowly, merging smoothly with well-rounded anterior end. Posterodorsal almost straight or weakly concave, also descending rather slowly. Posterior end rather narrow, normally rounded, occasionally with a feeble rostrum formed by an ill-defined ridge running from umbo and another, even weaker ridge somewhat lower down. Between the ends of these ridges the margin is almost straight. Ventral margin broadly convex. No lunule or escutcheon but a narrow, concave posterior area bounded by the rostral ridge. Concentric sculpture of linear grooves with broad, flat interspaces, not persisting onto posterior area but present over

rest of shell, tending to anastomose, especially distally. Spacing of grooves irregular. Hinge rather heavy, long, weakly angled below beak, anterior series with 18, posterior series with 15 tall, chevron-based teeth in adult shells, separated by deep, slightly oblique resilifer which does not project below hinge. Anterior adductor muscle scar large, ovate, posterior scar smaller, elongated horizontally. Pallial line descending somewhat obliquely from anterior end of posterior scar, forming a weak, triangular sinus. Rest of interior polished.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (l.v.)	18.2	12	4.5
Topotype (d.v.) (R.S.A. Colln)	20.5	12.4	9.7 (2 valves)

HOLOTYPE: TM 4114, N.Z. Geological Survey.

TYPE LOCALITY: McCullough's Bridge.

LOCALITIES: Tahu Member, McCullough's Bridge (only moderately common, but present in all collections); Highcliff Siltstone, McCullough's Bridge; GS 11,200, Kapua Tuffs, Waihao R. (subadult shell). Also recorded from Oamaru Diatomite (Runangan) (Maxwell in Edwards and Hornibrook, in prep.).

STRATIGRAPHIC RANGE: Kaiatan-Runangan.

REMARKS: Pseudoportlandia solenelloides (Marshall, 1919) (Hampden, Bortonian) grows to a larger size than tahuia (length up to 30 mm), its dorsal margins descend rather less steeply and its posterior end is broader, giving the shell a more malletioid shape.

Pseudoportlandia is known only from the Arnold Series in New Zealand and has been recorded from several Kaiatan-Runangan exposures

on the west coast of South Island as well as the Bortonian-Runangan of North Otago and South Canterbury.

Genus Ledaspina Marwick

1931 N.Z. Geol. Surv. Paleont. Bull. 13: 53.

Type species (original designation): Ledaspina stimulea Marwick, 1931, Miocene, New Zealand.

The status of Ledaspina is somewhat uncertain. Puri (in Moore 1969: N235) includes it in the synonymy of Nuculana s.l. without comment. Of the nuculanid taxa accepted by Puri, Ledella is probably closest to Ledaspina, Ledella messanensis (Sequenza) having a robust hinge very like that of stimulea. The writer has not seen undoubted specimens of messanensis and is unable to find good figures of its exterior or of its adductor muscle scar and pallial features, all of which are important in assessing taxonomic relationships in this family. Consequently, it seems wisest to regard Ledaspina and Ledella as distinct taxa for the time being.

Ledaspina stimulea has a close living relative in the abyssal species Spinula tasmanica Knudsen, 1970 (3580 m Tasman Sea, near New Zealand) which would be difficult to distinguish from some specimens of stimulea. Shape, hinge features and muscle scars are very similar in both species, but the fine concentric lamellae appear to be more widely spaced in tasmanica. Spinula filatovae Knudsen, 1967 (2312 m, Gulf of Aden) may also be related, but no figures are given of the interior features.

Ledella pakaurangiensis Laws, 1941 (Otaian, Pakaurangi) is another New Zealand Ledaspina; it may, however, be a synonym of stimulea.

Ledaspina knudseni n.sp. Pl. 2, figs. 19, 20.

DESCRIPTION: Shell very small, subelliptical, fragile, weakly rostrate, beak small, slightly opisthogyrous, subcentral. Antero-dorsal margin gently convex, descending moderately steeply, merging smoothly with ventral margin, anterior end well-rounded. Postero-dorsal margin almost straight, descending more slowly, obliquely truncated distally near the rostrum. Ventral margin convex except for a very weak concavity just below the feeble rostrum. No lunule or escutcheon, but a well-defined posterior area bounded by a distinct, rounded ridge that runs from the umbo to the rostrum. Concentric sculpture of thin, low lamellae spaced several times their width apart, relatively distinct on disc but weakening considerably on approaching the rostral ridge, bent back sharply on posterior area. Hinge rather narrow, ventral margin wavy, obtusely angled below beak, anterior and posterior series with about 12-13 fine teeth, separated by a broadly triangular resilifer. A short ligamental groove extends for about 4 teeth in front of beak. Adductor muscle scars rather indistinct, anterior scar apparently larger than posterior scar.

DIMENSIONS OF HOLOTYPE (l.v.): Length (est.) 3.5, height 2.4, inflation (1 valve) 0.7 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (probably Kaiatan).

LOCALITIES: GS 9480; GS 9508, Tahu Member, McCullough's Bridge (one broken left valve and subadult double-valved paratype); GS 4872, Port Elizabeth, Westland (Kaiatan).

REMARKS: Differs from L. stimulea in its more weakly rostrate form, lighter hinge and finer concentric sculpture. This is the oldest

record of the genus from New Zealand.

Genus Ledella Verrill and Bush

1897 Amer. Jour. Sci. (4) 3: 54.

Nom. subst. pro Junonia Seguenza, 1877, non Junonia Huebner, 1819.

Type species (by subsequent designation, Verrill and Bush, 1897): Leda messanensis Seguenza, 1877, Recent, Atlantic.

If the New Zealand nuculanids placed in Ledaspina (see above) should prove assignable to Ledella, then species like Ledella clifdenensis Powell, 1935 (Otaian-Clifdenian), L. longirostrata Maxwell, 1969 (Waitakian) and the species described below will need to be placed in another taxon. Comitileda Iredale, 1924 (type species, Leda miliacea Hedley, 1902) would appear to be the most suitable location.

Ledella brachyryncha n.sp. Pl. 2, figs. 17, 18.

DESCRIPTION: Shell very small, ovate, moderately inflated, beak small, opisthogyrous, somewhat behind middle. Anterodorsal margin gently convex, descending moderately steeply, merging smoothly with ventral margin; anterior end well-rounded. Posterodorsal margin somewhat straighter and not descending so steeply. Ventral margin broadly convex, except for a weak concavity near posterior end, forming a short, blunt rostrum. No lunule or escutcheon. Posterior area very weakly defined by an indistinct, broad well-rounded ridge running from beak to rostrum. No sculpture apart from very fine concentric striae and occasional growth ridges. Hinge narrow, weakly angled below beak, anterior series with 10, posterior series with 11 fine, chevron-based teeth, separated by a small, broadly triangular resilifer. Interior polished, muscle scar and pallial features

scarcely discernible.

DIMENSIONS (mm):	Length	Height	Inflation (1 valve)
Holotype (l.v.)	2.75	1.8	0.7
Paratype (l.v.)	3.0	1.8	0.6

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge. (Kaiatan) (holotype and 3 paratypes).

REMARKS: Ledella brachyryncha differs from L. longirostrata Maxwell and L. clifdenensis Powell in its much shorter rostrum. The length: height ratios for the holotype and largest paratype are 1.52 and 1.66 respectively, compared with 1.53-1.61 for L. clifdenensis and 1.72-2.00 for L. longirostrata (Maxwell 1969: 165). Such parameters are by themselves unsatisfactory indicators of the degree of rostration and must be used with caution.

This is the earliest record of the genus from New Zealand.

Genus Yoldiella Verrill and Bush

1897 Amer. Jour. Sci. (4) 3: 55-6.

Type species (original designation): Yoldia lucida Loven, 1846. Recent, North Atlantic.

When the writer transferred 3 Cenozoic and Recent New Zealand nuculanids from Ovaleda (= Sarepta) to Yoldiella, he noted that the new location was not entirely satisfactory (Maxwell 1969: 165). In particular, the type species, Y. lucida, is reported to have an external ligament, though no trace of such a feature has yet been observed on any of the New Zealand species. However, no more suitable location has so far suggested itself, despite the appearance of

the bivalve volume of the Treatise on Invertebrate Paleontology (Moore 1969). The section on nuculanids in that work unfortunately leaves much to be desired, particularly as many taxa are synonymised without figures of their type species being included so that workers can judge for themselves whether such an action is justified.

In the meantime, Yoldiella is used for a group of lightly built, ovate or subelliptical nuculanids with concentric sculpture of distant, weak ridges which are generally weak or absent from the central part of the disc.

Yoldiella malletioides n.sp. Pl. 2, figs. 13, 14.

DESCRIPTION: Shell very small, fragile, moderately inflated, malletiform or subelliptical; beak small, weakly opisthogyrous, at anterior two thirds. Anterodorsal margin gently convex, descending rather steeply, merging smoothly with ventral margin, anterior end well-rounded. Posterodorsal margin almost straight, descending slowly; posterior end broad, well-rounded, in some cases having a truncated appearance, junction with posterodorsal margin rounded. Ventral margin broadly convex, junction with posterior end marked by slight change in curvature. Hinge narrow, very obtusely angled, anterior series with 10, posterior series with 10-11 small, acutely chevron-based teeth, separated by a tiny triangular resilifer. Anterior adductor muscle scar moderately large, strongly bilobed in holotype, very indistinct in paratypes. Posterior scar small, pallial line with a broad, shallow rounded sinus. Exterior with very fine, distant ridges distally, otherwise smooth.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (r.v.)	3.6	2.4	0.7 (1 valve)
Paratype (d.v.)	3.0 (est.)	2.1	1.2 (2 valves)

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan) (holotype and 8 paratypes, some fragmentary).

REMARKS: Yoldiella ardgowanica (Powell, 1935) (Altonian, North Otago) has a light hinge like Y. malletioides, but differs in its more central beak and narrower posterior end. Y. otekaikensis Maxwell, 1969 (Duntroonian-Waitakian, North Otago) has a much heavier hinge than either ardgowanica or malletioides.

Genus Sarepta A. Adams

1860 Ann. Mag. nat. Hist. 3(5): 303.

Type species (original designation): Sarepta speciosa A. Adams, 1860, Recent, Japan.

Synonym: Ovaleda Iredale.

1925 Rec. Austral. Mus. 14: 248, 250.

Type species (original designation): Sarepta? tellinaeformis Hedley, 1901, Recent, south-east Australia.

Iredale proposed Ovaleda without any mention of its distinguishing characters. Powell (1935: 252) accepted Ovaleda as a distinct genus related to Sarepta, stating that it differed in having "feeble traces of a rostrum and a small broadly triangulate chondrophore with a normal resilium, quite unlike the elongate, narrow, oblique resilium of Sarepta". The writer has examined numerous specimens of tellinaeformis (from 110 m off Port Jackson, N.S.W.) and is unable to confirm Powell's diagnosis. Far from being rostrate, tellinaeformis has a subcircular or elliptical outline with the posterior margin only slightly less rounded than the anterior margin. The hinge is short and narrow with a comparatively large, triangular chondrophore

projecting somewhat below and bearing a narrow, oblique resilium, and as far as can be judged from figures, very similar in all features to that of Sarepta speciosa. Accordingly, the writer considers Ovaleda to be a synonym of Sarepta, following Thiele (1935: 788), Cotton (1961: 35) and Puri (in Moore 1969: N239).

Sarepta sp.

Two small specimens of a species of Sarepta from McCullough's Bridge may be conspecific with S. constricta (Marwick, 1942) which was described from Hampden (Bortonian). The more complete of the Waihao shells measures only 5.1 x 4.3 mm, whereas the holotype of constricta is 10 x 8 mm, making direct comparison difficult.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Genus Austrotindaria Fleming

1948 Trans. Roy. Soc. N.Z. 77(1): 72-3.

Type species (original designation): Austrotindaria wrighti Fleming, 1948. Recent, New Zealand.

When Fleming proposed the genus Austrotindaria, he compared it with four other nuculanoid groups lacking a resilium but bearing an external ligament, viz. Tindaria Bellardi, 1875, Neilonella Dall, 1881, Minormalletia Dall, 1908 and Protonucula Cotton, 1930. Of these, Neilonella /type species Leda (Neilonella) corpulenta Dall, 1881, Recent, Carribean/ resembles Austrotindaria in general shell-form and in having the hinge-line interrupted below the beak, but differs in the character of the ligament, which is amphidetic in Neilonella and opisthodetic in Austrotindaria. Tindaria (type species, T. arata Bellardi, 1875, Pliocene, Italy) also has an

opisthodetic ligament, but has a less elongate shell than Austrotindaria and has the hinge-line continuous beneath the beaks. Protonucula (type species, P. verconis Cotton, 1930, Recent, South Australia) is similar to Tindaria in hinge features and may be congeneric. Minormalletia /type species, Malletia (Minormalletia) arciformis Dall, 1908, Recent, E. Pacific/ has an amphidetic ligament.

At the time of its erection, Austrotindaria was known solely by the type species, but since then two further living species, A. benthicola Dell, 1956 and A. flemingi Dell, 1956, and a fossil form, A. aequata Marwick, 1965 (Nukumaruan), have been described. All three species, as well as the new species described below, agree with A. wrighti in ligamental features but there is some variation in the nature of the hinge. A. benthicola has a distinct gap in the hinge-line below the beak as in wrighti, but this gap appears to be absent in flemingi where tiny teeth are present beneath the beak. Marwick's figures of the hinge of A. aequata (Marwick 1965, Pl. 9, figs. 2, 6, 8) indicate that some specimens have the hinge thickened below the beak, whereas others are more typical. Similar variation is present in the new species described below. The significance of these hinge features is uncertain and several different stocks may be represented in the species currently included in Austrotindaria, or alternatively, the variation may be phenotypic in origin.

McAlester (in Moore 1969: N235) included Austrotindaria and Neilonella in the synonymy of Saturnia Seguenza, 1877 (type species, Nucula pusio Philippi, 1844), apparently overlooking the fact that the latter name is a junior homonym of Saturnia Schranck, 1802.

In most classifications of the Pelecypoda, genera like Tindaria, Neilonella, etc. are included in a family "Malletiidae", distinguished

from the Nuculanidae by the absence of a resilium, the ligament being predominantly external (see, for example, Moore 1969: N233, 235). Yonge (1939) showed many years ago that Malletia itself does not differ significantly in anatomical and functional features from "typical" nuculanids and suggested that the "Malletiidae" and Nuculanidae be merged in a single family. This conclusion was accepted by McAlester (1964: 397-8) who nonetheless suggested that taxa like Tindaria and Neilonella may not be closely related to Malletia or the other nuculanids. The writer shares Knudsen's view (1970) that there is no cogent conchological evidence at least, for separating those taxa with external ligaments only from "typical" nuculanids, some of which have both a resilium and an external ligament. Until such time as evidence to the contrary is found, it is proposed to include the former in the Nuculanidae.

Austrotindaria delli n.sp. Pl. 16, figs. 212, 213.

DESCRIPTION: Shell very small, ovate, inflated, beak at anterior 3/5ths. Anterodorsal margin slightly concave to gently convex, descending rather steeply; posterodorsal margin long, almost straight, descending more slowly. Anterior and posterior ends well-rounded, merging smoothly with the broadly and evenly convex ventral margin. No lunule or escutcheon. Sculpture of low, rounded concentric costae with narrow, sometimes linear interstices, usually subobsolete near beaks but fairly prominent elsewhere. Hinge long and narrow, obtusely angled; in some shells interrupted beneath beak, in others no definite gap but a short interval in which teeth appear to have undergone partial resorption, in yet others a short, smooth thickened area beneath beak. Anterior series with 10-12, posterior series with

12-15 fine chevron-based teeth, proximal ones usually obscure. Ligament opisthodetic, extending backwards for 4-6 teeth, occupying a shallow embayment in shell margin. Shell interior highly polished, adductor muscle scars feebly marked but apparently subequal; pallial line also obscure but apparently sloping backwards from the anterior end of the posterior scar and then swinging around parallel to the ventral margin, thus forming a weak sinus.

DIMENSIONS OF HOLOTYPE (r.v.): Length 3.3, height 2.4, inflation (1 valve): 0.7 mm.

HOLOTYPE: N.Z. Geological Survey

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

LOCALITIES: GS 9508 (holotype and about 45 paratypes); GS 9480, McCullough's Bridge (seven paratypes).

REMARKS: This species is very similar to Austrotindaria flemingi Dell, 1956 (Recent) and may be directly ancestral. A. flemingi grows to a larger size than any of the known species of delli (holotype of flemingi measures 4.8 x 3.6 x 1.3 mm), has a broader posterior end and less numerous teeth (9 anterior, 11 posterior). A related species with stronger concentric sculpture occurs abundantly in a Bortonian shellbed (S118/f608) in the South Branch, Waihao River.

Order ARCOIDA

Superfamily ARCACEA

Family ARCIDAE

Subfamily ANADARINAE

Genus Bathyarca Kobelt

1891 Systematisches Conch. - Cab. 390: 213.

Type species (by subsequent designation, Verrill and Bush, 1898; see Bowden and Heppell 1966: 114): Arca pectunculoides Scacchi, 1833, Recent, Mediterranean-North Atlantic.

Synonym: Microcucullaea Iredale

1929 Rec. Austral. Mus. 17: 159.

Type species (original designation): Bathyarca perversidens Hedley, 1902, Recent, New South Wales.

Bathyarca bellatula Marwick, 1942

1942 Bathyarca bellatula Marwick; T.R.S.N.Z. 72(3): 269-70, pl. 23, figs. 14, 15.

1966 Bathyarca bellatula; Fleming, N.Z. D.S.I.R. Bull. 173: 18, pl. 8, figs. 99, 100.

DIAGNOSIS: A small, subrectangular, highly inflated Bathyarca with sculpture of about 30 prominent narrow radial costae with occasional interstitial costellae, crossed by fine, distant concentric ridges, intersections finely spinose. Hinge with teeth continuous under beak. Inner margin finely crenulate.

DIMENSIONS (mm):	Length	Height	Inflation (1 valve)
Holotype (l.v.)	3.6	2.75	1.2
McCullough's Bridge specimen (l.v.) (GS 9508)	3.7	3.2	1.3
" " " "	4.2	3.3	1.7

HOLOTYPE: TM 4135, N.Z. Geological Survey.

TYPE LOCALITY: Hampden Beach (Bortonian).

LOCALITIES: Hampden; McCullough's Bridge: R.S. Allan Colln (one specimen), GS 9480 (one specimen), GS 9508 (Tahu Member) (six specimens).

STRATIGRAPHIC RANGE: Bortonian-Kaiatan.

REMARKS: Bathyarca bellatula differs radically from other New Zealand species of Bathyarca. The subrectangular shape which gives this species a strong resemblance to a minute Arcopsis, the strong radial sculpture, crenulated margins and the continuity of teeth along the hinge all suggest that it should be referred elsewhere, although in view of the rather confused state of arcid taxonomy it is probably wisest to leave it in Bathyarca for the time being.

Family CUCULLAEIDAE

Genus Cucullaea Lamarck

1801 Syst. Anim. sans Vert.: 116.

Type species (by subsequent designation, Children, 1823): Cucullaea auriculifera Lamarck, 1801 (= Arca labiata Solander, 1786), Recent, China.

Subgenus Latiarca Conrad

1862 Proc. Acad. nat. Sci. Philad.: 289.

Type species (by subsequent designation, Stoliczka, 1870): Cucullaea gigantea Conrad, 1830, Eocene, Maryland.

Cucullaea (Latiarca) cf. waihaoensis Allan, 1926.

1926 Cucullaea waihaoensis Allan; T.N.Z.I. 56: 345, pl. 77, fig. 7.

1926 Cucullaea waihaoensis; Allan, T.N.Z.I. 57: 289, 291.

1937 Cucullaea cf. waihaoensis; Finlay & Marwick, N.Z.G.S. Pal. Bull. 15: 98.

1960 Cucullaea (Latiarca) waihaoensis; Marwick, N.Z.G.S. Pal. Bull. 33: 9, 12.

1966 Cucullaea (Latiarca) waihaoensis; Fleming, N.Z. D.S.I.R. Bull. 173: 17.

HOLOTYPE: Canterbury Museum.

TYPE LOCALITY: Waihao Downs (Bortonian).

LOCALITIES: Waihao Downs (bluffs opposite "Waihao Downs" homestead and abandoned railway cutting) (Bortonian); Hampden (Bortonian); several localities in North Otago in Tapui Glauconitic Sandstone (Bortonian) (Gage 1957: 111); "Matau fauna", Castle Hill Shaft, Kaitangata (?Late Dannevirke Series) (Finlay and Marwick 1937: 97); Otaio Gorge (?Late Dannevirke Series) (Marwick 1960: 12). Allan (1926a: 345) also recorded C. waihaoensis from "the Tahuian beds at McCullough's Bridge". The few specimens seen from the Tahu Member are small (length <40 mm), those from the underlying Ngapuke Member are larger but poorly preserved. All are probably conspecific with the Waihao Downs species, but the material is inadequate for confident comparison. Boreham (1965: 11) has noted that specimens of C. waihaoensis do not seem to have longer hinges than the Duntroonian species C. attenuata Hutton, 1873, implying that the Eocene form is not worthy of separation, but the writer prefers to recognise C. waihaoensis as a distinct species until sufficient material is available for critical comparison.

Superfamily LIMOPSACEA

Family LIMOPSIDAE

Genus Limopsis Sassi

1827 Giorn. Sci. Ligustico 1: 476.

Type species (by subsequent designation, Gray, 1847): Arca aurita Brocchi, 1814, Miocene-Recent, Mediterranean and eastern Atlantic.

Newell (in Moore 1969: N265) has subdivided the genus Limopsis into two subgenera, Limopsis s.str. for species "without radial ornamentation, inner margins not crenulate", and Pectunculina for those with "radial costellae" and crenulated margins. A long list of subjective synonyms is given for both Limopsis s.l. and L. (Pectunculina). Unfortunately, radial sculpture is present on Limopsis aurita and indeed, on virtually every species of Limopsis, whether or not they have crenulated margins, so the presence or absence of radials is scarcely a reliable diagnostic character. Newell's choice of synonyms of Pectunculina is equally unfortunate, as it includes several taxa with smooth margins (i.e. Senectidens Iredale, 1931, Versipella Iredale, 1931 and Limopsista Finlay and Marwick, 1937).

It should be emphasised that recognition of a number of subgeneric groups in the genus Limopsis is desirable, especially for the numerous Australasian Cenozoic and Recent species in which there is considerable variation in shell outline, inflation, sculpture, ligamental features and details of adductor muscle scars. Finlay and Marwick (1937: 25) suggested that many of the larger New Zealand Cenozoic species probably belonged to Senectidens, although Beu (1969: 487) considers the type species, S. dannevigi Iredale, to be a "normal" Limopsis. Until the New Zealand species can be compared directly with the type species of the rather numerous Australian "genera"

proposed by Iredale, any attempt to place them in supraspecific units must be premature.

Limopsis waihaoensis Allan, 1926. Pl. 1, figs. 3-5.

1926 Limopsis waihaoensis Allan; T.N.Z.I. 56: 346, pl. 77, figs. 8a, b.

1926 Limopsis waihaoensis; Allan, T.N.Z.I. 57: 291.

1966 Limopsis (Limopsis) waihaoensis; Fleming, N.Z. D.S.I.R. Bull. 173: 19.

DESCRIPTION: Shell small, rather fragile, juveniles almost circular, adults inequilateral, of ovate to subquadrate outline. Beak small, slightly opisthogyrous. Dorsal margins subequal or with posterior margin distinctly longer, both straight, gently sloping away from beak. Posterior margin oblique, gently convex, junction with ventral margin rounded, junction with posterodorsal margin generally abrupt and sharp. Anterior and ventral margins merged in a broadly convex curve, junction with anterodorsal margin rounded or very obtusely angled. Concentric sculpture weak, consisting of very fine, distant grooves medially, becoming low ridges on flanks. On distal portions of adult shells, grooves merge into rather irregularly spaced growth ridges. Radial sculpture also weak, strongest on flanks, especially posteriorly, consisting of indistinct threads, sometimes continuous between concentric ridges but usually visible only on the ridges themselves which are thereby weakly crenulated. On distal portions of some adult shells radial sculpture becomes more distinct, forming low, broad rounded costellae with linear interstices. Hinge plate narrow, assymetrical, arched or subangled posterior to beak, 5 or 6 grooved teeth in each series, proximal teeth usually lamellar or

tubercular, others, apart from the outermost, weakly chevron-based. Anterior teeth almost vertical, the proximal 1 or 2 extending below the resilifer. Posterior teeth more oblique, distal ones usually horizontal. Cardinal area long and narrow with fine longitudinal ridges, resilifer narrow, triangular. Anterior adductor muscle scar small, ovate, set at lower edge of hinge plate, myophoric ridge weakly to strongly developed. Posterior scar about twice as large, ovate to subquadrate, usually distinctly impressed on anterior side. Pallial line very indistinct, area just inside with numerous fine, rounded radial ridges, rest with minute papillae. Inner margin of shell sharply bevelled and smooth in adults and most juveniles, but finely crenulated in two small shells (height 2.8 mm).

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (r.v.) (fide Allan 1926)	7.5	6.5	-
Hypotype (r.v.) (GS 9508)	7.5	6.2	2.4
" " " "	7.2	7.0	1.8

HOLOTYPE: Auckland Institute and Museum (ex H.J. Finlay Colln).

TYPE LOCALITY: McCullough's Bridge.

LOCALITIES: McCullough's Bridge (abundant in Tahu Member and well represented in all collections); Oamaru Diatomite (Maxwell in Edwards and Hornibrook, in prep.) (Runangan); Trig. M, Totara (Runangan).

STRATIGRAPHIC RANGE: Kaiatan-Runangan.

REMARKS: Limopsis waihaoensis belongs to a compact little group of New Zealand species that also includes L. propeinvalida Laws, 1939 (Otaian, Pakaurangi) and L. invalida Marwick, 1928 (Opoitian, Chatham Is.), characterised by small size, weak sculpture and delicate hinge. These species appear to be closer to L. aurita than the other New

Zealand species which are generally larger with stronger sculpture and more robust hinges. A related species is present in a Bortonian shellbed (S118/f608) from the South Branch, Waihao River.

Genus Notolimopsis Maxwell

1969 Trans. Roy. Soc. N.Z. (Geol.) 6(13): 167-8.

Type species (original designation): Notolimopsis pulchra Maxwell, 1969, Oligocene, New Zealand.

Notolimopsis hampdenensis (Marshall, 1919). Pl. 2, figs. 15, 16.

1919 Limopsis hampdenensis Marshall; T.N.Z.I. 51: 233, pl. 15, figs. 12, 13.

1919 Sarepta tenuis Marshall; T.N.Z.I. 51: 233, pl. 15, fig. 9.

1927 Limopsis tenuis; Finlay, T.N.Z.I. 57: 446.

1927 Limopsis hampdenensis; Finlay, T.N.Z.I. 57: 448.

1943 Limopsis hampdenensis (= L. tenuis); Marwick, T.R.S.N.Z. 73(3): 181.

1966 Limopsis hampdenensis; Fleming, N.Z. D.S.I.R. Bull. 173: 19.

1969 Notolimopsis hampdenensis; Maxwell, T.R.S.N.Z. (Geol.) 6(13): 167.

DESCRIPTION: Shell very small, inequilateral, ovate to subelliptical, strongly inflated. Beak small, orthogyrous or very weakly opisthogyrous, at about anterior 3/5ths. Prodissoconch semicircular, smooth, rather flat, easily worn off shell. Dorsal margins straight, horizontal, posterodorsal considerably longer than anterodorsal margin. Posterior margin very gently convex, sloping backwards, junction with posterodorsal margin subangled; anterior and ventral margins not differentiated, strongly convex, merging smoothly with

posterior margin, junction with anterodorsal margin rounded. Concentric sculpture consisting of narrow shallow grooves with weakly convex interspaces, frequently obsolete proximally, tending to change into narrow ridges on posterior flank. Radial sculpture confined to posterior portion of shell, consisting of weak threads slightly more prominent than the concentric ridges. Hinge narrow, arched, assymetrical; anterior series with 4-6 weakly chevron-based, fine teeth, posterior series with 6-7 teeth, less oblique than anterior teeth and more lamellar. A short edentulous stretch between series. Cardinal area long and narrow, with a small triangular resilifer beneath beak. Anterior adductor muscle scar small, triangular, set high up near lower end of hinge, myophoric ridge weak; posterior scar larger, situated lower down, weakly impressed or almost flush with shell interior. Pallial line very faint, area inside with minute pits and extremely fine radial striae. Margins smooth, bevelled.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype S. tenuis (l.v.)	3.8	3.4	1.2
Lectotype L. hampdenensis (r.v.)	4.0	3.6	1.2
Hypotype (GS 9508) (l.v.)	3.6	3.2	1.2

TYPES: Sarepta tenuis Holotype TM 4171, N.Z. Geological Survey. Limopsis hampdenensis Lectotype (here selected) (Marshall 1919, Pl. 15, fig. 13) TM 4170, N.Z. Geological Survey.

TYPE LOCALITY: Hampden Beach, North Otago (Bortonian) (both S. tenuis and L. hampdenensis).

LOCALITIES: Hampden; McCullough's Bridge - R.S. Allan Colln (one shell), GS 9480 (11 shells), GS 9508, Tahu Member (about 50 shells, many double-valved).

STRATIGRAPHIC RANGE: Bortonian-Kaiatan.

REMARKS: The types of S. tenuis and L. hampdenensis are somewhat larger than any of the McCullough's Bridge shells, but otherwise fall within the range of variation shown by the Kaiatan sample. Small specimens of Limopsis waihaoensis are readily distinguished from N. hampdenensis by their more circular shape, more polished shell with less prominent concentric sculpture and weaker radial sculpture which is present over the whole disc rather than confined to the posterior part of the shell. Notolimopsis hampdenensis is similar in shape to N. caelata Maxwell, 1969 (Duntroonian) but differs in its much weaker sculpture.

Family PHILOBRYIDAE

Genus Lissarca Smith

1877 Phil. Trans. Roy. Soc. Lond. 168: 168.

Type species (by subsequent designation, Suter 1913; see Nicol 1966: 36): Arca (Lissarca) rubrofusca Smith 1877, Recent.

Synonym: Austrosarepta Hedley.

1899 Proc. Linn. Soc. N.S.W. 25: 430.

Type species (original designation): Austrosarepta picta Hedley, 1899, Recent, N.S.W.

Reasons for synonymising these taxa are given by Bergmanns (1970).

Lissarca sp.

Three very small left valves from McCullough's Bridge represent the earliest record of the genus from New Zealand. The largest specimen, which was about 2.5 mm long when complete, lacks the beak

and hinge area, but the others show the typical resilifer and vertically striated cardinal area. Neither have any trace of hinge teeth, probably reflecting their immature nature. The upper and lower parts of the posterior margin are crenulated by narrow internal costae like those in the living New Zealand species L. benthicola (Dell, 1956). The semicircular prodissoconch is sculptured by extremely fine radial striae, the adult shell by concentric grooves.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

REMARKS: Lissarca is usually included in the Limopsidae, apparently on account of its ligamental features and hinge teeth, but its affinities are more likely to be with the Philobryidae. This is borne out by the presence of a typically philobryid prodissoconch on the species described above.

Order MYTILOIDA

Superfamily MYTILACEA

Family MYTILIDAE

Subfamily MODIOLINAE

Genus Amygdalum Megerle von Muehlfeld

1811 Ges. nat. Fr. Berlin, Mag. 5(1): 69.

Type species (by monotypy): Amygdalum dendriticum Megerle von Muehlfeld, 1811, Recent, West Indies.

Amygdalum sp.

A tiny, internal mould of a modiolinid from the Kapua Tuffs is fairly confidently referred to Amygdalum. The specimen, which is a left valve measuring only 7.5 x 4.2 mm, has the elongate form, long

straight posterodorsal margin and divergent, gently convex ventral margin typical of the genus. The Waihao shell may be conspecific with an Amygdalum from the approximately coeval Waiareka Tuffs at Lorne, North Otago.

Amygdalum is sporadically distributed throughout much of the New Zealand Cenozoic, Fleming (1959a: 169-70) recording it from localities ranging in age from Duntroonian to possibly Castlecliffian. It has also been recorded from the Bortonian of Geraldine district (Marwick in Wellman 1953: 42).

LOCALITY: GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan).

Order PTERIOIDA

Superfamily PECTINACEA

Family PECTINIDAE

CLASSIFICATION OF NEW ZEALAND INTERNALLY-RIBBED PECTENS

The internally costate New Zealand Cenozoic pectens have posed taxonomic problems of one sort or another ever since Zittel (1864) described Pecten aucklandicus from Lower Miocene beds at Orakei Bay, Auckland. Hutton (1873: 32) described a second species as Pecten zitteli, a name that was used indiscriminately for virtually all pectens with internal costae until Marwick (1928: 451-2) noted that two distinct groups could be recognised in the New Zealand (and Australian) Cenozoic. He placed species like zitteli that have subequal ears lacking a byssal notch and both valves almost smooth in Parvamussium, and those with a pronounced byssal notch and with discrepant valves in which the left valve but not the right have radial sculpture in Variamussium Sacco, 1897. Later (1931: 64) he considered Ctenamusium a more apt location for the latter group and described a new species as C. vafer.

Subsequent authors have accepted Marwick's generic locations without question, paying more attention to the taxonomic problems at the specific level in the zitteli group (Boreham 1965: 35-6, Beu 1970c: 214).

The publication of Hertlein's excellent summary of the Pectinidae in the Treatise on Invertebrate Paleontology (Moore 1969: N348-73) has greatly clarified generic limits within this diverse family, and a glance at his figures and diagnoses is sufficient to show that Parvamussium has been wrongly used by New Zealand workers for some 40 years. The type species of Parvamussium is in fact very similar in size, sculpture and nature of the byssal sinus to the New Zealand species previously included in Ctenamusium, whereas zitteli and related forms clearly belong in the genus Propeamussium de Gregorio, 1884. Species of Propeamussium are generally larger and less circular than those of Parvamussium and have a much weaker byssal notch, when this is present at all. The external sculpture and the character of the internal costae are less reliable criteria for distinguishing the two groups. Radial sculpture is usually present on the left valve of Parvamussium, but in some species, e.g. P. paradoxum (Maxwell, 1969) and P. maorium Dell, 1956), it is entirely absent or reduced to microscopic striae. In the case of P. paradoxum, both valves have fine concentric sculpture, albeit somewhat coarser in the left valve, and so resemble Propeamussium. Internal costae are generally rather constant in number in a given species (except in Parvamussium paradoxum where they range from 15-21) but the distance they extend from the umbo to the ventral margin is quite variable and not, by itself, a reliable way of distinguishing Parvamussium from Propeamussium. Beu (1970c: 214) has pointed out that in small specimens of P. zitteli (less than 25 mm high), the costae reach almost to the margin, whereas in

larger shells the costae extend only two thirds the distance. Parvamussium maorium, which has a marked byssal notch and so cannot belong with zitteli in Propeamussium, despite the fact that it grows much larger than other New Zealand Parvamussium, has internal costae which vary in much the same way, except that in the largest shells (up to 22 mm high) they reach only one third of the distance to the margin (Dell 1963: 206). Dell's figures of the holotype and paratype of maorium (Dell 1956b: Pl. 4, figs. 30, 31) show the costae extending much further in the right valve than in the left; a similar situation is present in one of the species recorded below.

The New Zealand species of Parvamussium and Propeamussium are listed below, together with the ages of the holotypes.

Genus Propeamussium de Gregorio, 1884 (type species, by original designation; Pecten (Propeamussium) ceciliae de Gregorio, 1884, Miocene, Sicily).

Propeamussium zitteli (Hutton, 1873). Whaingaroan.

P. papakurense (Clarke, 1905). Otaian.

Genus Parvamussium Sacco, 1897

Parvamussium paradoxum (Maxwell, 1969). Duntroonian.

P. aucklandicum (Zittel, 1864). Otaian.

P. vafer (Marwick, 1931). Lillburnian.

P. maorium Dell, 1956. Recent.

At least three species of Parvamussium are represented in the material from McCullough's Bridge, judging mainly by the sculptural features of the left valves. Although all three species are almost certainly new, they are not named at this stage, partly because of

the uncertainty surrounding the identity of the Miocene species P. vafer. The holotype (from GS 1342, Waikura Stm, Ngatapa S.D.) is a somewhat battered right valve lacking the auricles, and with interior obscured, whereas the paratypes figured by Marwick (1931: figs 56, 57) are from a locality about 10 miles distant, albeit of similar age. The figured left valve (fig. 56) has distinctive sculpture of closely spaced radial costellae, reticulated by equally finely-spaced fine concentric lamellae. Unfortunately, there is no guarantee that this is conspecific with the holotype of P. vafer. In the writer's experience, the right valve in New Zealand Parvamussium is very conservatively sculptured and unless definitely associated with a left valve, almost worthless for firm identification.

Genus Parvamussium Sacco

1897 I. Moll. Terr. terz. Piemonte Liguria 24: 48.

Type species (original designation): Pecten duodecimlamellatus Bronn, 1831, Miocene, Italy.

Synonym: Ctenamusium Iredale.

1929 Rec. Austral. Mus. 17: 164.

Type species (original designation): Amusium thetidis Hedley, 1902, Recent, N.S.W.

(Numerous additional synonyms are given by Hertlein (in Moore 1969: N350-1)).

Parvamussium sp. A. Pl. 16, fig. 215.

In this species the left valve has nepionic sculpture of fine distant concentric lamellae; on the adult shell the concentric lamellae

become more closely spaced and are crossed by about 50 fine radial costellae. The intersections of the radials and concentrics bear minute spines. Internal costae number 10-11 and stop well before the ventral margin. The right valve is less inflated than the left valve and shorter dorso-ventrally. External sculpture consists of very fine, distant concentric ridges. Internal costae reach almost to the ventral margin. In general appearance, the right valve closely resembles the holotype of P. vafer.

LOCALITIES: GS 9480 (4 r.v.); GS 9508 (1 d.v., 8 l.v., 4 r.v.). Besides this material there are a number of right valves which differ from those described above in having concentric lamellae considerably more closely spaced, especially distally. These may represent the right valve of one of the species described below or merely a variant of sp. A. - GS 9508 (7 valves), GS 9480 (1 valve), R.S. Allan Colln. (1 valve).

Parvamussium sp. B.

This is represented by a single damaged left valve measuring 4.2 x 3.9 mm, lacking radial sculpture entirely but with concentric sculpture of fine, closely spaced ridges. There are only 12 internal costae; otherwise this shell closely resembles the left valve of Parvamussium paradoxum (Maxwell) (with 15-21 costae).

LOCALITY: GS 9508, Tahu Member.

Parvamussium sp. C.

The third species of Parvamussium is represented by a left valve (length 5.1 mm) lacking the umbo and auricles. Sculpture consists of about 80 fine radial costellae, some with interstitial

threads, crossed by extremely fine, much weaker concentric ridges. There are 14 internal costae.

LOCALITY: GS 9508, Tahu Member.

Genus Duplipecten Marwick

1928 Trans. N.Z. Inst. 58: 451.

Type species (original designation): Pecten (Pseudamussium) waihaoensis Suter, 1917, Middle Eocene, New Zealand.

Duplipecten was originally proposed as a subgenus of Lentipecten Marwick, 1928 (type species Pecten hochstetteri Zittel, 1864 amend. Hutton, 1873) but it is unlikely that the two taxa are closely related. The following morphological differences are especially significant:

1) The right valve of Duplipecten is somewhat more inflated than the left valve, the opposite of the situation in Lentipecten.

2) The right valve ears in Duplipecten are separated from the disc by deep channels, whereas in Lentipecten they are separated by weak grooves.

3) The pallial line lies much further from the shell margin in Duplipecten.

4) The adductor muscle scar is much larger in Lentipecten than in comparable-sized specimens of Duplipecten.

These differences, together with the discovery of a smooth pecten (Lentipecten n.sp.), similar to Lentipecten hochstetteri, in a Bortonian shellbed in the upper Waihao R. (S118/f610), are good reasons for considering Lentipecten and Duplipecten distinct genera. A tendency to reduce and eventually lose radial sculpture has been has been noted in many groups of pectens and is certainly not a

reliable guide to phyletic relationship.

Duplipecten parki (Marwick, 1942)

1942 Lentipecten parki Marwick; T.R.S.N.Z. 72(3): 270, pl. 23, figs. 7, 10, 13.

1966 Lentipecten parki; Fleming, N.Z. D.S.I.R. Bull. 173: 21, pl. 18, figs. 179-181.

DIAGNOSIS: A medium-sized pecten with both valves smooth apart from fine concentric striae and growth lines and extremely feeble radial grooves. Left valve noticeably less inflated than right. Dorsal margins of left valve auricles quite straight, anterior and posterior margins of auricles descending almost vertically, making an angle of about 90° with dorsal margin. Right valve with auricles serrated dorsally and separated from disc by a strongly marked step that becomes a deep channel distally. Byssal fasciole scarcely defined, tending to be concave upwards rather than convex.

DIMENSIONS OF HOLOTYPE (l.v.): Length 57, height 55, inflation 8 mm.

HOLOTYPE: TM 4248, N.Z. Geological Survey.

TYPE LOCALITY: Hampden Beach, North Otago (Bortonian).

LOCALITIES: Hampden; GS 2572, Waihao Downs (Marwick 1942: 270), also left bank Waihao R. opposite "Waihao Downs" (Bortonian); GS 2873, Ten Mile, Greymouth (Bortonian or Kaiatan); GS 9480, 9580, McCullough's Bridge (Kaiatan); GS 11,449, greensands below "phosphatic" band, McCullough's Bridge (Bortonian) (1 adult left valve).

STRATIGRAPHIC RANGE: Bortonian-Kaiatan.

REMARKS: Marwick proposed Duplipecten for a discrepantly-sculptured pecten from the Waihao Greensand, Waihao Downs, described by Suter

(1917: 69) as Pecten (Pseudamussium) waihaoensis. The holotype of waihaoensis consists of a double-valved shell in which the left valve (virtually complete) has prominent broad, ray-like radial costae which become obsolete distally, while the right valve is quite smooth apart from fine concentric striae. Very similar shells, some double-valved, have been collected from a bed with abundant Limopsis campa Finlay in the abandoned railway cutting near "Waihao Downs" homestead, in the river cliffs immediately downstream for some 200 m and in a high cliff on the opposite bank about 300 m distant. The costae vary considerably in strength, being reduced to rays with virtually no surface relief in some shells, but all samples include some prominently costate left valves. About 1 km downstream, on the left bank of the Waihao R., in beds that are apparently stratigraphically higher (probably near the top of the Lower Waihao Greensands) is a pecten with right valve identical to typical waihaoensis but having the left valve smooth. These shells are identical to specimens of parki from Hampden and are almost certainly derived from Duplipecten waihaoensis by loss of the radial costae. "L." parki is accordingly removed from Lentipecten (with which it has little in common apart from absence of sculpture) to Duplipecten. As in any evolving lineage, the specific limits must be blurred in intermediate populations, but as a working model there seems little problem in differentiating between populations (or more correctly, samples) in which most left valves are distinctly costate (i.e. waihaoensis), and those with no costate (but possibly feebly rayed) valves (parki).

The two adult shells collected by the writer from McCullough's Bridge (one from the lower greensands, i.e. Bortonian, and the other from GS 9480, i.e. probably Kaiatan) are left valves identical to those from Hampden and the upper beds at Waihao Downs. Allan

(1926c: 291) listed Pecten huttoni (Park) (= Lentipecten hochstetteri) and P. waihaoensis from McCullough's Bridge; the former record is probably based on a left valve, the latter on a right valve of Duplipecten parki.

Genus Chlamys Roeding

1798 Museum Boltenianum 2: 161.

Type species (by subsequent designation, Herrmannsen, 1847): Pecten islandicus Mueller, 1776, Recent, North Atlantic.

Chlamys (s.l.) n.sp.

A small pecten, not uncommon in washings from the Tahu Member, McCullough's Bridge, apparently represents a species of Chlamys related to C. williamsoni (Zittel, 1864) (Whaingaroan) and C. chathamensis (Hutton, 1873) (Duntroonian). Sculpture is of strong radial costae of squarish section with interspaces of similar width, crossed by very fine concentric striae. Costae 29-31 on left valve (3 shells) and 32-34 on right (3 shells) compared with 20-27 on Chlamys chathamensis and 24-27 on C. williamsoni (Boreham, 1965: 21-22). Both chathamensis and williamsoni have scaly radial costae but the Tahu Member shells, probably all immature (the largest is 8.0 mm high), lack strong concentric sculpture, which may develop at a later stage of growth as in C. chathamensis.

LOCALITIES: GS 9480, GS 9508 Tahu Member, McCullough's Bridge (Kaiatan).

Genus Serripecten Marwick

1928 Trans. N.Z. Inst. 58: 449.

Type species (original designation): Pecten hutchinsoni Hutton, 1873, Oligocene-Miocene, New Zealand.

Serripecten tahuianus Laws, 1935

1935 Serripecten tahuiana Laws; T.R.S.N.Z. 65: 23-4, pl. 4, fig. 2.

1966 Serripecten tahuianus; Fleming, N.Z. D.S.I.R. Bull. 173: 21.

DESCRIPTION: Shell of moderate size, rather robust, right valve distinctly more inflated than left, pronounced disc gape below anterior ears. Length of disc greater than height. Right valve auricles large, dorsal margins slightly inclined upwards from horizontal, crenulated by concentric lamellae. Byssal notch deep, rounded, forming a prominent fasciole; ctenolium weakly developed, only 2 teeth visible on holotype. Posterior auricle with 6 narrow, scaly radial costellae, anterior auricle with 2 ill-defined, almost smooth radials. Disc with 22 narrow but prominent rounded primary radial costae, most pairs with a secondary costa appearing between them about 1/3rd distance from umbo to ventral margin. Some secondary costae near the middle of the disc become almost as strong as primaries towards the ventral margin, but others remain subordinate. On the holotype, both primaries and secondaries bear prominent squamae from an early stage of growth but on the topotype (possibly worn) they bear little more than weak transverse ridges. Other concentric sculpture very subdued, consisting of weak lamellae between the costae. Camptonectes sculpture apparently restricted to auricles and early part of disc. Adductor muscle scars strongly impressed, striate and non-striate portions separated by a rather broad ridge. Interior of disc weakly

plicated by external costae especially on ventral margin. Resilifer rather deep, cardinal crura prominent. Left valve apparently with anterior auricle slightly larger than posterior auricle. The latter bears 4 squamose radial costae with an intercostal reticulate microsculpture. Anterior auricle missing on topotype. Disc with about 23 narrow primary radial costae, secondaries appearing about 12 mm from umbo and tertiaries, which are mostly present on the flanks of the primary costae, at about half-way across disc. All costae finely squamose. Interior obscurely plicated. Adductor muscle scar strongly impressed.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (r.v.)	36.4	36.1	7.7
Topotype (GS 9507) (r.v.)	39.2	36.6	8.3
" " (l.v.)	40.2	36.9	6.9

HOLOTYPE: Auckland Institute and Museum, ex C.R. Laws Colln.

TYPE LOCALITY: McCullough's Bridge, probably from lower part of Ngapuke Member (Bortonian).

LOCALITIES: GS 9507, base of Ngapuke Member (Bortonian) (1 double-valved shell damaged about auricles, agreeing in preservation with holotype); ?GS 3273, collected by H.W. Wellman, 1944, apparently from the same horizon (1 large, battered double-valved shell).

REMARKS: The above description is based on the holotype and the specimen from GS 9507. The shell from GS 3273 is considerably larger (length left valve 60 mm) with a superficially different appearance due to the tendency for secondary costae (and in the case of the left valve, tertiary costae as well) to become as strong as the primaries distally. In the right valve the primary costae are similar in number to those in the two small shells but are not so prominent.

Muscle scar features in the large shell are similar to those in the holotype and small topotype.

The size and general appearance of the shell from GS 3273 suggests relationship to S. hutchinsoni. The only important sculptural difference in the left valve is the stronger radial costae on the auricles of the Eocene species. The right valve, however, has weaker primary costae than similar-sized individuals of S. hutchinsoni, with secondary costae appearing at an earlier stage of growth. The primary costae on the holotype of S. tahuianus, however, are similar in number and strength to those on young right valves of S. hutchinsoni from the Gee Greensand, Oamaru district (Otaian-Altonian), although they are much smoother in hutchinsoni than in tahuianus. Auricular shape and sculpture and adductor muscle scar features are similar in the two species.

It is tempting to consider Serripecten tahuianus as the ancestor of S. hutchinsoni, but in fact it is merely one of a poorly-understood complex of related species, largely undescribed, that existed in the mid-Eocene and Oligocene. Several lineages are probably represented in the available material (mostly from North Otago-South Canterbury but also from Westland and Northland). Serripecten enfieldensis (Marwick, 1926) (Lorne, Kaiatan) is the only other species so far named; it differs from tahuianus in having much smoother primary costae with secondaries appearing at a later stage of growth. The species recorded from the Bortonian of Pahi, Northland by Fleming (1950: 241) as "Serripecten n.sp. aff. tiorioriensis Marwick" is also closely related to tahuianus, but as far as can be judged from the rather poor material available has more numerous primary costae on the right valve (38-40 according to Fleming), less well developed

secondary costae and much smoother radials. Fleming suggested that the Pahi species fell between tiorioriensis (a Waipawan species from Chathan Is.) and tahuianus in sculptural development, but this seems to be too simple an interpretation in view of the large number of right primary costae in the Pahi form. The species from Pahi seems, in fact, to be closer to an undescribed species from the Deborah Tuffs (Whaingaroan) of Kakanui.

Serripecten marwicki n.sp. Pl. 8, figs. 91-3.

DESCRIPTION: Shell small for genus, only moderately robust, right valve distinctly more inflated than left, no disc gape below anterior ears. Dorsal margins of right auricles almost horizontal, weakly crenulated. Byssal notch deep, v-shaped, fasciole concave, bordered by a finely denticulate ctenolium. Posterior auricle with 7 fine, scaly radial costellae, anterior auricle with about 3 costellae. Disc with about 28-32 narrow primary radial costae, a secondary costa appearing between each pair of primaries at about 10 mm from umbo, each secondary becoming flanked by a tertiary riblet at approximately 20-25 mm in middle of disc, considerably later on flanks. Secondary costae quickly become as strong as primaries. All radials finely squamose, giving the shell a distinctive rasp-like appearance. Camptonectes microsculpture extending over auricles and most of disc. Very weak concentric ridges appear between costae distally. Inner margin of disc finely crenulate except near auricles. Adductor muscle scars only weakly impressed, clearly separated into striate and non-striate sections. Resilifer deep, cardinal crura strong. Left valve with anterior auricle slightly larger than posterior, dorsal margins almost horizontal. Posterior auricle with 7 finely squamose radial costellae, anterior auricle with 6 similar radials.

Disc with about 26 narrow primary radial costae, secondary and tertiary costae appearing at about the same stage as in the opposite valve. Tertiaries only slightly weaker than primaries and secondaries distally. All radials delicately squamose. Camptonectes microsculpture as on right valve. Inner margin finely crenulate, adductor muscle scar slightly impressed.

DIMENSIONS (mm)	Length	Height	Inflation
Holotype (l.v.)	35.5	34.0	6.6
" (r.v.)	34.5	34.5	10.3
Paratype (R.S. Allan Colln) (r.v.)	34.5	34.0	9.5
" (GS 5643) (l.v.)	32.5	30.7	7.2

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9507, base of Ngapuke Member, McCullough's Bridge (Bortonian).

LOCALITIES: McCullough's Bridge - GS 9507 [holotype (d.v.) and paratype (r.v.)]; GS 3273 [paratype (l.v.)]; GS 5643 [paratype (l.v.)]; R.S. Allan Colln [paratype (r.v.)]. [All of these specimens are probably from the lower part of the Ngapuke Member (i.e. Bortonian)]; Waihao Downs, coll. R.S. Allan, 1932 (Bortonian) [paratype (r.v.)].

STRATIGRAPHIC RANGE: Bortonian.

REMARKS: Serripecten marwicki differs abundantly from the sympatric S. tahuianus. Its valves are less robust and more strongly inflated and lack the pronounced disc gape of tahuianus. The auricles are smaller in S. marwicki and more finely sculptured, have a less prominent byssal fasciole and more strongly developed ctenolium. Radial sculpture on the disc of Serripecten marwicki is much finer

than in S. tahuianus and tends to be similar on both valves rather than obviously discrepant. Finally, the adductor muscle scars are less strongly impressed in S. marwicki. Serripecten marwicki is not particularly similar to any other species known to the writer, differing in its markedly inflated valves and fine radial sculpture which tends to be similar on both left and right valves.

Superfamily ANOMIACEA

Family ANOMIIDAE

Subfamily ANOMIINAE

Genus Anomia Linnaeus

1758 Syst. Naturae ed. 10: 700.

Type species (by subsequent designation, Schmidt, 1818): Anomia ephippium Linnaeus, 1758, Recent, Europe.

Anomia sp. indet.

1967 Anomia sp. indet.; Beu, Trans. Roy. Soc. N.Z. (Zool.) 9(18): 231.

A juvenile shell recorded by Beu (1967b) from McCullough's Bridge is one of the few records of Anomia from New Zealand before the Oligocene. Since Beu's review of the family was published, a single moderately large valve of an Anomia measuring 48 x 31.5 x 13.5 mm has been collected from a Bortonian shellbed (GS 9958) in the South Branch, Waihao R. near "Pentland Hills". This is indistinguishable from Neogene and Recent specimens of A. trigonopsis Hutton, 1877 which Beu (1967b: 231) recorded from Duntroonian to Recent in New Zealand. The McCullough's Bridge shell may be conspecific.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Superfamily LIMACEA

Family LIMIDAE

Genus Limea Bronn

1831 Ergeb. nat. Reisen 2: 623.

Type species (by monotypy): Ostrea strigilata Brocchi, 1814, Miocene, Austria.

Limea (Limea) allani n.sp. Pl. 1, figs. 6, 7.

DESCRIPTION: Shell small, ovate, moderately oblique, strongly inflated, beak small, near middle of dorsal margin. Dorsal margins short, straight, horizontal. Anterior margin gently convex, sloping forwards, merging smoothly with the strongly convex ventral margin. Posterior margin also lightly convex, junction with ventral margin very feebly and bluntly subangled. Just below the dorsal margins, both anterior and posterior margins become weakly concave, thus forming poorly defined auricles. Radial sculpture consisting of numerous narrow, low, rounded costellae obsolete on ears and near umbo but uniformly distributed over rest of shell. About 48 costellae on holotype, almost smooth on early part of shell, finely beaded by concentric growth ridges on latter part, a fine beaded threadlet appearing between each pair of costellae about 2 mm from umbo. Cardinal area broadly triangular with a wide deep triangular resilifer beneath beak. Auricles with narrow, oblique lamellar teeth, 7 anterior, 6 posterior. Adductor scar large, subcircular, pallial line distinct, well within shell, away from the finely crenulated margins.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (r.v.)	5.4	6.7	1.9
Paratype (l.v.)	3.0	3.5	0.9

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (probably Kaiatan).

LOCALITIES: McCullough's Bridge - GS 9480 (holotype), GS 9508 (two paratypes).

REMARKS: Probably the "Limea neozelanica Allan MS" of Allan (1926c: 291). The only other New Zealand Cenozoic species of Limea so far described is L. chathamensis Marwick, 1928 (Opoitian, Chatham Is); this differs from the new species in having a more pronounced bulge on the posterior margin and broader, more triangular costellae and in lacking the gemmulation of the interstitial threadlets. Escalima regularis Powell, 1955 (Recent) has a more strongly subangled posterior margin than either chathamensis or allani; this is probably why this species was placed in Escalima rather than Limea. /Cox in Moore 1969: N390) treats Escalima as a subgenus of Limea/. Mantellum inconspicuum Marwick, 1926 (Kaiatan, Lorne) may also be a species of Limea; unfortunately, the holotype is not well-preserved, sculptural details are not clear and the hinge is obscured by matrix.

A species of Limea very similar to allani in the Waihao Greensands at Waihao Downs (Bortonian) differs primarily in its less strongly gemmulated primary costellae and much weaker interstitial threadlets.

Genus Limatula Wood

1839 Mag. Nat. Hist. (n.s.) 3: 235.

Type species (by subsequent designation, Gray, 1847): Pecten subauriculata Montagu, 1808, Recent, Europe.

Limatula sp.

A very fragmentary valve of a Limatula from McCullough's Bridge belongs to the long-ranging and widespread Limatula suteri group, characterised primarily by the nature of the internal ribs (Finlay 1927: 454, Dell 1956b: 27). In L. suteri (Dall) (Recent) this consists of a strong median rib, flanked on either side by another strong rib, whereas in L. maoria Finlay (Recent) there is a median groove with a rib on each side. The Waihao shell has a prominent median rib with a pronounced but narrow groove along the top, bordered on each side by a strong groove of similar width to the rib. The ribs bordering the grooves are weakly defined. External sculpture consists of narrow, triangular costae, much weaker on the flanks than in the middle half of the shell. Limatula trulla Marwick, 1926 (Kaiatan, Lorne) has broader, more rounded costae than the Waihao shell and almost completely smooth flanks. The internal ribs are much weaker and discernible only near the ventral margin.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Superfamily OSTREACEA

Family GRYPHAEIDAE

Subfamily PYCNODONTEINAE

Genus Pycnodonte Waldheim

1835 Bull. soc. imp. Nat. Moscou 8: 118.

Type species (original designation): Pycnodonte radiata Waldheim, 1835, Upper Cretaceous, Crimea.

Synonym: Gigantostrea Sacco

1897 I Moll. Terr. terz. Piemonte Liguria 23: 14.

Type species (original designation): Ostrea gigantica Solander, 1766, Eocene, England.

According to Stenzel (in Moore 1971: N1107), Gigantostrea is a synonym of Pycnodonte.

Pycnodonte (Pycnodonte) mackayi (Suter, 1917). Pl. 9, figs. 105-8.

1917 Ostrea (s.str.) mackayi Suter; N.Z.G.S. Pal. Bull. 5: 71-2, pl. 8, fig. 3, pl. 13, fig. 2.

1926 Ostrea mackayi; Allan, T.N.S.I. 67: 291.

1928 Gigantostrea mackayi; Finlay, T.N.Z.I. 59: 266.

1966 Gigantostrea mackayi; Fleming, N.Z. D.S.I.R. Bull. 173: 23.

DESCRIPTION: Shell moderately large, strongly inequivalve, left valve considerably larger and more inflated than right. Shell with pronounced lamellar structure, more apparent in right valve where it forms a strong imbricate pattern, than in left valve where the shell layers are flat-lying and overlap smoothly. Layers of alternating solid and vesicular calcite, the latter producing a microscopically spongy appearance on weathered surfaces. Relative thickness of

layers varies from shell to shell and within each shell. Prismatic layer, if ever present, presumably very thin and easily removed. Left valve strongly convex, bowl-shaped, thick-shelled, especially near umbo, apparently almost equilateral in subadult shell, but becoming elongated dorso-ventrally (as in holotype) or antero-posteriorly (as in figured hypotype) in adult. Attachment scar rather small, suggesting that this species spent most of its life lying free on the sea-bed. (Holotype attached to right valve of another individual of the same species). Posterior sulcus rather weak and crude but distinguishable on all reasonably complete specimens; posterior ear of variable development, stronger in figured hypotype than in other shells seen. Umbo low, triangular, projecting somewhat horizontally over hinge, but scarcely produced dorsally. Sculpture (apart from irregular, rounded welts) consisting of weak, strongly appressed growth lines and subobsolete radial grooves. Ligamental area broadly triangular, somewhat more than half occupied by the shallowly concave resilifer; bourrelets triangular, flat, separated from shell margins by narrow, deep grooves in the well-preserved hypotype. /Resilium in hypotype apparently became bifid at some stage late in growth, so forming a resilifer in shape of an inverted Y - compare figure given by Stenzel (in Moore 1971: N975, fig. J16) of a Lower Miocene oyster/. Commissural shelf broad, best defined dorsally, almost coincident with outline of opposing valve. Catachomata restricted to small areas on shelf just below hinge, short, branching slightly near outer ends. Umbonal cavity small in subadult shell, almost entirely absent in adult. Adductor muscle scar subcircular, only slightly longer than high, dorsal margin convex. Adductor myostracum at least partially preserved in most specimens seen, present as a thin dark brown layer, apparently composed of small

prisms arranged with long axes normal to the surface. Quenstedt muscle scar moderately large, situated just below lower edge of hinge, similar in appearance and structure to adductor scar. Proximal gill weal clearly shown on figured hypotype, not visible on other shells. Right valve smaller and thinner-shelled than left valve, almost flat or somewhat concave, normally with well-defined ears that are marked off from disc by distinctive sculpture. (On the figured hypotype the posterior ear is further demarcated by a strong radial ridge corresponding to posterior sulcus of left valve). Dorsal margin straight, moderately long, umbo very low, ligamental area broadly triangular, sharply inclined to rest of shell, making an angle of about 60° with ligamental area in opposing valve. Concentric sculpture of numerous imbricating growth lamellae, less evident on ears than on disc; radial sculpture of fine, weak, discontinuous costellae. Ears in at least half of the specimens seen bearing small rounded tubercles and short, irregularly branching ridges that appear to represent external traces of former anachomata. Anachomata seen clearly only on hypotype, near distal edges of ears, similar to corresponding catachomata. Other internal features, apart from the obsolescence of the commissural shelf, like those in left valve.

DIMENSIONS (mm):	Length	Height	Inflation
Holotype (l.v.)	65.5 (incomplete)	77.5	35.5
" (r.v.)	46	50	8
Hypotype (l.v.)	111.5 (slightly incomplete)	81	45
" (r.v.)	78	63	15

HOLOTYPE: TM 4283, N.Z. Geological Survey.

TYPE LOCALITY: GS 642, "Waihao Bridge", i.e. McCullough's Bridge, collected A. McKay. (Probably from Lower greensands, i.e. Bortonian).

LOCALITIES: Unnamed member, Waihao Greensands, below cemented band, McCullough's Bridge (Bortonian): GS 642 (holotype); GS 1987 (figured hypotype); GS 3272 (four damaged valves, representing three shells); GS 11,449 (subadult left valve); GS 11,450, upper 2 m of Ngapuke Member (Kaiatan) (right valve). This species has not been collected from the Tahu Member, as far as the writer is aware. There are no definite records of the species away from McCullough's Bridge, although Marwick and Olson (in Gage 1957: 111) list it from 3 Bortonian localities in North Otago. Of these, only the specimen (a small right valve) from GS 3771, Kakanui R., has a subcircular adductor muscle scar and vesicular shell structure and is therefore referrable to the Pycnodonteinae; unfortunately, it is too small to be identified confidently as P. mackayi.

STRATIGRAPHIC RANGE: Bortonian - Kaiatan.

REMARKS: This species is referred to Pycnodonte s.str. rather than to Crenostrea Marwick, 1931 (type species, Ostrea wullerstorfi Zittel, 1864, Landon Series, New Zealand) because radial sculpture is virtually absent, the low umbo scarcely projects above the hinge and the chomata are not straight but branching. Stenzel (in Moore 1971: N1107) classes Crenostrea as a subgenus of Pycnodonte.

Phygraea Vyalov, 1936 (type species Gryphaea frauscheri Vyalov, 1936 = G. pseudovesicularis Guembel, 1861, Paleocene, Austria) (also classed as a subgenus of Pycnodonte by Stenzel: N1107) is another possible location for O. mackayi. However, although the left valve of O. mackayi resembles that of P. pseudovesicularis in overall shape and general smoothness, it differs in having a definite posterior sulcus (and consequently, a posterior ear) and a nearly straight rather than a concave, geniculate posterodorsal margin. Judging by

the diagnoses given by Stenzel, these features indicate that O. mackayi should be referred to Pycnodonte s.str. rather than to Phygraea.

No other species of Pycnodonte s.str. have been described from New Zealand. Ostrea wollastoni Finlay, 1924 (= O. incurva Hutton, 1873 non O. incurva Nilsson, 1827) (Landon or Pareora Series, "Oamaru), referred with O. mackayi to Gigantostrea by Finlay (1928: 266) and Fleming (1966: 23) has a deeply impressed, reniform adductor muscle scar and lacks a vesicular structure and is therefore not referrable to the Pycnodonteinae. Ostrea wollastoni should instead be referred to the Ostreidae (as interpreted by Stenzel 1971), possibly to the taxon Solidostrea Vyalov, 1948 (type species Ostrea hemiglobosa Romanovsking, 1884, Eocene, Afghanistan). Stenzel (in Moore 1971: N1150, 1153) tentatively synonymises Solidostrea with Flemingostrea Vrendenburg, 1916 (type species Ostrea flemingi d'Archiac & Haime, 1853, Lower Eocene, India), but O. hemiglobosa has the adductor muscle scar situated considerably closer to the umbo than typical Flemingostrea.

The deep, bowl-shaped left valve and the relatively small attachment scar of Pycnodonte mackayi suggests that it spent most of its life lying free on, or partly imbedded in, the sea-bottom. The great discrepancy in valve size noted in this species (maximum overlap is about 25 mm in figured hypotype) may be an adaptation to keep the commissure protected from sediment transported along, or close to the substrate interface by traction currents. In life, there was presumably a broad conchiolin fringe along the margin of the right valve, helping to keep the shell firmly sealed (see Stenzel, in Moore 1971: N977-8). Such an adaptation would also ensure that the left valve remained more massive than the right valve, thereby keeping the centre of gravity low and so maintaining the shell's stability.

Order VENEROIDA

Superfamily LUCINACEA

Family THYASIRIDAE

Genus Parathyasira Iredale

1930 Rec. Austral. Mus. 17: 392.

Type species (original designation): Parathyasira resupina Iredale, 1930, Recent, N.S.W.

Parathyasira flemingi n.sp. Pl. 9, fig. 102.

DESCRIPTION: Shell rather small, subquadrate, equivalve, moderately inflated, beaks at anterior two thirds. Anterodorsal margin lightly concave, posterodorsal margin gently convex, descending rather steeply. Anterior margin gently convex, ventral margin subangled medially, posterior margin short, slightly concave. Lunule of moderate size, gently concave but not impressed, marked off from disc by change in slope rather than a distinct ridge. Escutcheon very sharply distinguished from rest of shell, very steep and deeply impressed, strongly concave, simulating a ligamental groove. Posterior area well-defined, sharply impressed below disc, gently convex, no posterior sulcus evident. Two weakly defined ridges from umbones to the antero-ventral junction and the middle of the ventral margin. Concentric sculpture of broad, low, rounded folds with slightly wider concave interspaces, not persisting onto posterior area, weakening abruptly in front. Radial sculpture, superimposed on concentric folds, restricted to a very thin, easily removed outer shell layer and consisting of numerous fine thread-like rows of minute papillae. Interiors of shells not seen.

DIMENSIONS (mm):	Length	Height	Inflation (2 valves)
Holotype (d.v.)	10.0	9.9	4.8
Paratype (")	10.6	10.9	6.0
Paratype (")	7.2	7.4	3.9

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (holotype and two paratypes).

REMARKS: Differs from the living New Zealand subspecies P. resupina neozelanica Iredale, 1930 in its more quadrate shape and strong concentric sculpture. Parathyasira r. resupina has stronger radial sculpture and less prominent, less rounded concentrics. This is the only fossil record of the genus from New Zealand known to the writer.

Superfamily LEPTONACEA

Family ERYCINIDAE

Genus Erycina Lamarck

1805 Ann. Mus. Hist. nat. Paris 6(36): 413 (validated by ICZN Opinion 427).

Type species (subsequent designation, Stoliczka, 1871): Erycina pellucida Lamarck, 1805, Middle Eocene, France.

Subgenus Hemilepton Cossmann

1911 Act. Soc. Linn. Bordeaux 65: 166.

Type species (original designation): Hemilepton longifossula Cossmann, 1911, Lower Miocene, France.

Erycina (Hemilepton) aotea n.sp. Pl. 1, figs. 8, 9.

DESCRIPTION: Shell small, fragile, elliptical, moderately inflated; beak small, at anterior three fifths. Anterodorsal margin moderately convex, merging smoothly with well-rounded anterior margin; posterodorsal margin gently convex, descending rather steeply, posterior margin rather broad, moderately convex. Ventral margin broadly convex, junctions with anterior and posterior margins well-rounded. Surface rather corroded in all specimens but apparently smooth apart from fine concentric striae and microscopically pseudopunctate sculpture. Hinge very light, right valve with a long, lamellar anterior lateral tooth parallel to the anterodorsal margin, a single small tubercular cardinal tooth fused to it directly below the beak. Posterior lateral tooth much shorter than anterior lateral, situated at the upper end of a long, narrow platform and separated from rest of hinge by a short, horizontal, internal ligament groove. Left valve with a rather long lamellar anterior lateral, well depressed below shell margin level. Two small tubercular cardinal teeth, the posterior one minute. Posterior lateral tooth rather short, behind a short ligament groove. Behind the posterior lateral the narrow hinge plate is weakly grooved. Interior with a few narrow concentric ridges, other internal features not visible.

DIMENSIONS (mm):	Length	Height	Inflation (1 valve)
Holotype (r.v.)	6.3	5.1	1.4
Paratype (l.v.)	6.2	4.8	1.3

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (Kaiatan).

LOCALITIES: GS 9480 (holotype and paratype); GS 9508, Tahu Member, McCullough's Bridge (2 paratypes).

REMARKS: Assignment of this species to Hemilepton is rather tentative, as the type species has two cardinal teeth in both valves, according to the diagnosis and figures given by Chavan (in Moore 1969: NS19-20, fig. E25, 8a, b) whereas aotea has only one right cardinal. In other respects the McCullough's Bridge species appears to be quite similar to longifossula.

Superfamily CARDITACEA

Family CARDITIDAE

Subfamily CARDITESINAE

Genus Glyptoactis Stewart

1930 Acad. Nat. Sci. Philadelphia Spec. Publ. 3: 151, 152.
Type species (original designation): Venericardia hadra Dall, 1903, Middle Miocene, Florida.

Subgenus Fasciculicardia Maxwell

1969 (July) Trans. Roy. Soc. N.Z. (Geol.) 6(13): 173.
Type species (original designation): Venericardia subintermedia Suter, 1917, Lower Miocene, New Zealand.

Chavan's recent classification of the Carditidae (in Moore 1969: N548-58) includes a number of radical changes. Many taxa which have long been considered subgenera of Venericardia have been afforded full generic status while others have become subgenera of other taxa.

In several cases these taxa are separated at the subfamilial level from Venericardia. Glyptoactis in particular is treated as a full genus in the new subfamily Carditesinae, with Claibornicardia Stenzel and Krause, 1957 and Baluchicardia Chavan, 1969 [= Baluchicardia Heaslip, 1968 = Baluchicardia Rutsch and Schenck, 1941 (nomen nudum)] as subgenera. Each of these taxa are characterised by tripartite (or fasciculate) radial costae, although the strength of the paracostal cords varies considerably within each group (see Heaslip, 1968). If Chavan's classification is accepted, then Rotundicardia Heaslip, 1968 and Fasciculicardia Maxwell, 1969 should also be treated as subgenera of Glyptoactis, as these taxa have a similar sculptural pattern.

The writer (Maxwell 1969: 173) distinguished Fasciculicardia from Glyptoactis on differences in sculpture, dentition and the nature of the lunule. Heaslip's excellent monograph (1968) has greatly clarified the taxonomic limits of Glyptoactis and related North American taxa, so that the writer's conclusions need some modification. Most of the species of Glyptoactis treated by Heaslip have 19-21 radial costae, but one Lower Miocene form, G. nodifera nodifera (Kellum, 1926) has 20-25 costae, thus overlapping somewhat with the extreme range of 22-32 costae recorded in species of Fasciculicardia. In general, the costae are considerably heavier in species of Glyptoactis, particularly the younger forms, than in Fasciculicardia. Lunular development varies considerably in species of Glyptoactis; as noted by the writer, the lunule of the type species is inconspicuous and hidden by the umbo, but in other species it is as prominent as in Fasciculicardia (i.e. pouting strongly in front of the umbo). Differences in dentition between the two groups are more constant and reliable than either the sculptural or lunular features. The left anterior cardinal (and hence the corresponding right valve socket) is considerably more

strongly developed in species of Fasciculicardia than in any of the species of Glyptoactis figured by Heaslip. An additional diagnostic feature, apparently unique to Glyptoactis, is a supplementary "tooth" formed on the left posterior cardinal tooth by "flexion of the lunule" (Heaslip 1968: 110).

Rotundicardia Heaslip, 1968 (type species, Venericardia rotunda Lea, 1833) is an early Paleocene to early Oligocene North American group that resembles Fasciculicardia in number of radial costae (extreme range of 18-34) and most features of dentition. Shape is the most important difference, species of Rotundicardia having a subrounded, equilateral (or "rotund") form with minimal posterior truncation. Species of Fasciculicardia by contrast, are somewhat elongated anteroposteriorly and have a distinct posterior truncation. In view of the differences in stratigraphic range (Fasciculicardia is recorded from Middle Eocene to Middle Miocene), geographic distribution and morphological details, the two groups are best regarded as subgenerically distinct.

Glyptoactis (Fasciculicardia) n.sp.

A fragmentary right valve lacking the hinge is similar to the Bortonian species G. (Fasciculicardia) acanthodes (Suter, 1917) from Waihao Downs but differs in its broader, more closely spaced radial costae which are flanked by unusually heavy paracostal cords. An undescribed species from the Wharekuri Greensand, head of Lake Waitaki (Duntroonian) has costae of similar width and spacing, but considerably less well-developed paracostal cords.

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Glyptoactis (? Fasciculicardia) flemingi n.sp. Pl. 8, figs. 94, 95.

DESCRIPTION: Shell rather small, rounded-trigonal, moderately inflated, beak high, at anterior three quarters. Anterodorsal margin steep, slightly concave, posterodorsal margin gently convex, also descending rather steeply. Anterior margin not distinguished from broadly convex ventral margin; posterior end weakly truncated, posterior margin weakly convex, junction with posterodorsal margin subangled. Posterior area weakly defined, slightly less convex than disc. Lunule small, cordate, pouting, smooth apart from weak growth lines. Escutcheon, if present, very narrow, scarcely distinguishable from ligament groove. Radial sculpture of 22 costae, narrow and of triangular section on posterior area, broader and of rounded-squarish section on rest of shell, weakening quickly near anterodorsal margin. Intercostal spaces concave, slightly wider than costae on posterior area, equal to or somewhat narrower than costae on rest of shell. Costae becoming weaker in relief near ventral margin. Costae near the umbo corroded but over rest of shell smooth apart from a few weak concentric growth ridges. Numerous fine concentric wrinkles in intercostal spaces. Left valve with small, erect triangular anterior cardinal tooth and a long, narrow, gently curved posterior cardinal. A small tubercular anterior lateral at lower end of lunule and a much weaker posterior lateral and a shallow socket above, at end of hinge. Anterior adductor muscle scar reniform, posterior scar ovate. A small, depressed pedal muscle scar just above anterior adductor, posterior pedal scar confluent with posterior adductor.

DIMENSIONS OF HOLOTYPE (l.v.): Length 20.8, height 21.0, inflation 8 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9507, immediately above "phosphatic" band, Ngapuke Member, McCullough's Bridge (Bortonian).

LOCALITIES: GS 9507 (holotype); R.S. Allan Colln, McCullough's Bridge (3 small shells, one double-valved, referred tentatively to this species, are of uncertain provenance).

REMARKS: This is the species referred to by the writer (Maxwell 1969: 173) as being "closely similar to bartrumi", originally described from the Pahi Greensands (Bortonian). It differs from bartrumi in its less rounded, more trigonal form and narrower, more widely spaced and smoother radial costae. The hinge of bartrumi is unknown.

Assignment of flemingi to Fasciculicardia is very tentative, as neither the holotype nor the small, well-preserved shells from the Allan collection show any trace of paracostal cords. Weakly tripartite costae are, however, present on some individuals of a related, undescribed venericard from a Bortonian shellbed with abundant corals in the Pareora R. (S111/f687). These have narrower and more widely spaced costae than flemingi but agree in dentition and lunular features. It is noteworthy that well-preserved specimens have intercostal sculpture of radial rows of minute papillae in addition to the concentric wrinkles; similar papillae are visible on one of the small McCullough's Bridge shells and on topotypes of G. (Fasciculicardia) acanthodes. The costae on the Pareora shells are for the most part smooth apart from weak growth ridges, but on well-preserved specimens strong tubercles are visible on the costal crests near the umbo. Marwick (1960: 13) noted this change in sculpture on Bortonian shells from GS 6077, Mt Horrible, a locality very close to S111/f687, and concluded that they were close to acanthodes. The writer regards the Pareora species and flemingi as members of a short-lived group that

was derived from a species of Fasciculicardia resembling acanthodes. Other members of the group may be bartrumi and a small, finely sculptured species that occurs in abundance near the top of the Waiareka Tuffs (Kaiatan or Runangan) on the south side of Cape Wanbrow, Oamaru.

Family CONDYLOCARDIIDAE

Subfamily CONDYLOCARDIINAE

Genus Condylocuna Iredale

1936 Rec. Austral. Mus. 19: 272.

Type species (original designation): Condylocardia projecta Hedley, 1902, Recent, New South Wales.

Condylocuna subaequilateralis (Maxwell, 1966)

1966 Condylocardia subaequilateralis Maxwell; N.Z.J.G.G. 9(4): 442, figs. 3, 4, 19.

1969 Condylocuna subaequilateralis; Maxwell, T.R.S.N.Z. (Geol.) 6(13): 176.

DIAGNOSIS: A trigonal, almost equilateral Condylocuna with dorsal margins of similar length, well-developed hinge and concentric sculpture of closely-spaced, somewhat overhanging ridges.

DIMENSIONS OF HOLOTYPE: Length 2.9, height 2.7 mm.

HOLOTYPE (l.v.): TM 3862, N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (Kaiatan).

LOCALITIES: GS 9480 (holotype and 5 paratypes); GS 9508, Tahu Member, McCullough's Bridge (6 specimens, 2 double-valved).

REMARKS: Specimens of Condylocuna from GS 9481, Lorne (Kaiatan), tentatively referred to subaequilateralis by Maxwell (1966: 442-3), differ in their more elongate shape and having the concentric ridges waved rather than regularly arcuate. They almost certainly represent a new species.

Superfamily CRASSATELLACEA

Family CRASSATELLIDAE

Genus Eucrassatella Iredale

1924 Proc. Linn. Soc. N.S.W. 49(3): 202.

Type species (original designation): Crassatella kingicola Lamarck, 1805, Recent, south-east Australia.

Eucrassatella (Eucrassatella) cf. australis (Hutton, 1873). Pl. 9, fig. 99.

1873 Astarte australis Hutton; Cat. Tert. Moll.: 25.

1914 Astarte australis; Suter, N.Z.G.S. Pal. Bull. 2: 47, pl. 13, fig. 5, pl. 17, fig. 2.

1926 Spissatella australis; Finlay, T.N.Z.I. 56: 256.

1935 Crassatellites tripliciter Laws; T.R.S.N.Z. 65: 23, pl. 4, figs. 1, 1a.

1937 Spissatella cf. australis; Finlay and Marwick, N.Z.G.S. Pal. Bull. 15: 99-100, pl. 14, fig. 7.

1960 Spissatella aff. australis; Marwick, N.Z.G.S. Pal. Bull. 33: 12-13, pl. 1, figs. 3, 5.

1965 Spissatella australis (= C. tripliciter); Boreham, N.Z.G.S. Pal. Bull. 37: 52-3, pl. 14, figs. 6, 7, 8.

1966 Spissatella australis; Fleming, N.Z. D.S.I.R. Bull. 173: 24, pl. 26, figs. 254-5

DIAGNOSIS: A moderately large, robust Eucrassatella that is relatively truncated posteriorly, so that some shells are rounded-trigonal, subequilateral in shape. Concentric sculpture of narrow rounded costae near the umbo, usually becoming obsolete within 15 mm of the beak but in some specimens persisting well into adult stage on anterior part of shell. Internal ventral margin usually smooth, occasionally weakly crenulated.

DIMENSIONS (mm):	Length	Height	Inflation (1 valve)
Hypotype (l.v., GS 176 fide Boreham 1965: 54)	52	43	-

HOLOTYPE (A. australis): TM 2861, N.Z. Geological Survey. Holotype C. tripliciter, Auckland Institute and Museum.

TYPE LOCALITY: A. australis; Kakahu, near Geraldine (Bortonian). C. tripliciter; Waihao Downs (Bortonian).

LOCALITIES: ?Late Dannevirke Series: GS 480 "Island Sandstone", Waihao R.; GS 759, Castle Hill Shaft, Kaitangata; Otaio Gorge. Bortonian: Kakahu; GS 176, Black Point, Bortons, Waitaki Valley; Waihao Downs; S118/f610, South Branch, Waihao R. near "Pentland Hills"; Bland's Bluff, Ashburton R.
Kaiatan: GS 9480, 9508, McCullough's Bridge (young shells only); GS 11,200, Kapua Tuffs (young double-valved shell).

STRATIGRAPHIC RANGE: ?Late Dannevirke Series - Kaiatan.

REMARKS: The assignment of australis to Spissatella by Finlay (1926: 256) has not been questioned by subsequent workers. Examination of a large suite of well-preserved shells from a Bortonian shellbed in the Waihao R. (S118/f610), however, leaves the writer in little doubt as to its close relationship to the Australasian post-Eocene species of Eucrassatella s.str. The large, robust shell, concentric sculpture

largely confined to a small area around the umbo and comparatively strongly convex ventral margin are features that support its inclusion in Eucrassatella rather than Spissatella. The weakly crenulated ventral margin present in some specimens of australis is probably a reflection of its derivation from a species of the typically Northern Hemisphere genus Crassatella Lamarck, 1799, as implied by Laws in his use of Crassatellites.

Spissatella Finlay, 1926 (type species, Crassatella trailli Hutton, 1873) is closely related to Eucrassatella s.str. and should probably be treated as a subgenus, following Chavan (in Moore 1969: N567). Species of Spissatella are generally smaller; the largest New Zealand species is S. subobesa (Marshall and Murdoch, 1919), measuring up to 55 mm in length, although the Australian Cenozoic species S. maudensis (Pritchard, 1903) is larger, measuring up to 68 mm in length (Darragh 1965: 111). They are usually more sharply truncated posteriorly, less inflated, and have less convex ventral margins than Eucrassatella s.str. Sculpture normally persists over the whole shell, though in some species (e.g. S. scopalveus Finlay, 1926) it is obsolete on the adult. In hinge features, muscle scars, etc., Spissatella is very similar to Eucrassatella, although the right anterior cardinal tooth is usually somewhat better developed in Spissatella. Although all of the distinguishing features are rather variable and not reliable individually, taken together they form a "gestalt" that allows easy differentiation of the two groups in the majority of cases.

The largest of the shells from McCullough's Bridge is a left valve measuring only 18.4 x 15.5 mm, with concentric sculpture of narrow costae persisting almost to the ventral margin but largely obsolete on the posterior area. In shape and sculpture it falls

within the considerable range of variation noted in the Bortonian sample from S118/f610 and is considered to be conspecific. The Kapua Tuffs specimen is smaller (11.9 x 9.0 mm) but otherwise similar. The small size of these specimens may be related to the depth at which they lived; Verco (1907) recorded "small and poor" specimens of Eucrassatella donacina (Lamarck) from depths of 40 and 100 fathoms in South Australia and normal sized shells from 15-20 fathoms (Verco 1905: 169).

Superfamily CARDIACEA

Family CARDIIDAE

Subfamily PROTOCARDIINAE

Genus Nemocardium Meek

1876 Dept. Inter. Rep. U.S. geol. Surv. Terr. 9: 167.
Type species (subsequent designation, Sacco, 1899): Cardium semiasperum Deshayes, 1858, Eocene, France.

Nemocardium (Nemocardium) carteri n.sp. Pl. 9, figs. 103, 104.

ETYMOLOGY: Named for Dr R.M. Carter, University of Otago, who kindly allowed the writer to describe this fine shell.

DESCRIPTION: Shell of moderate size, quite strongly inflated, rounded-subquadrate, beaks prominent, subcentral. Anterodorsal margin lightly convex, junction with anterior margin well rounded; posterodorsal margin almost straight, junction with the broad gently convex posterior margin subangled. Ventral and anterior margins in one smooth curve, junction with posterior margin rounded. Posterior third of shell sharply marked off from rest by abrupt change in sculpture, so defining a posterior area. Radial sculpture on

posterior area consisting of 31 narrow, flattish topped low costae with interspaces equal to, or slightly narrower than the costae distally, tending to be linear proximally. Costae become indistinct towards posterodorsal margin. Sprouting from the anterior half of each costa are small, rather irregular tubercles, occasionally subcylindrical but usually elongated radially, with a weak longitudinal groove on the crest. Tubercles appear to be arranged at regular intervals on each costa but show no obvious alignment between adjacent costae. Remainder of shell with numerous fine very fine costellae with linear interstices, distinct on corroded areas but visible only as fine lines corresponding to the intercostellal grooves on unweathered shell surface. Concentric sculpture consisting of very fine threads and on distal half, rather irregular prominent rounded growth ridges which do not persist onto posterior area. Hinge moderately heavy, right valve with a very small anterior cardinal in the form of a ridge on the dorsal surface of the recessed socket for the left anterior cardinal. Posterior cardinal prominent, peg-like, almost directly below beak, with a short and rather narrow oblique socket behind. Two anterior lateral teeth, a small tubercle dorsally, separated from a short horizontal tooth by a deep socket. Posterior lateral subhorizontal, somewhat larger than the lower anterior lateral tooth and separated from posterodorsal margin by a deep, narrowly triangular socket. Ligament groove apparently rather short, extending about the length of the posterodorsal margin. Left hinge damaged, consisting of a slightly oblique, strong triangular anterior cardinal and a small tubercular posterior cardinal tooth with a deeply recessed socket directly below. Anterior lateral tooth (or teeth) not preserved, posterior lateral short and rather low, situated near shall margin, with a shallow socket below. Anterior and ventral margins very finely crenulated internally, posterior margin with coarser but

still fine crenulations. Other internal features not seen.

DIMENSIONS OF HOLOTYPE (r.v.): Length 33, height 31, inflation 12.5 mm.

HOLOTYPE: A double-valved shell with right valve almost complete, left valve consisting of beak and hinge area only; OU 8467, Geology Dept, University of Otago, collected by J.D. Campbell and R.M. Carter.

TYPE LOCALITY: Lower greensand, McCullough's Bridge (Bortonian).

REMARKS: It is a moot point whether this species should be included in Nemocardium s.str., hitherto unrecorded from New Zealand, or in the endemic taxon Varicardium Marwick, 1944 (type species, Cardium patulum Hutton, 1873). Marwick (1944: 266) distinguished Varicardium from Nemocardium by its larger, more solid shell, by its strong anterior and ventral concentric ridges and by its lack of tubercles on the radial costae of the posterior area. In fact, well-preserved specimens of Varicardium patulum from the Lill Sand (Lillburnian) at Clifden retain tiny tubercles on the anterior edges of the posterior costae, though these are much smaller than those on N. carteri or any of the Northern Hemisphere species included in Nemocardium s.str. Although treated as a full genus by Marwick (1944), Boreham (1965: 59) and Fleming (1966: 28), Varicardium is more aptly regarded as a subgenus of Nemocardium, following Keen (in Moore 1969: N859).

The small size and strong posterior costal tubercles suggest that N. carteri belongs to Nemocardium s.str. whereas the strong concentric growth ridges indicate relationship with patulum. Nemocardium carteri may well be ancestral to Varicardium (first recorded from the Duntroonian) but on the basis of the strong costal tubercles, considered to be the most reliable of the diagnostic features mentioned, it is here included in Nemocardium s.str.

Subgenus Pratulum Iredale

1924 Proc. Linn. Soc. N.S.W. 49: 182.

Type species (original designation): Cardium thetidis Hedley, 1902, Recent, N.S.W.

Nemocardium (Pratulum) semitectum Marwick, 1926

1926 Nemocardium semitectum Marwick; T.N.Z.I. 56: 312, pl. 72, fig. 8.

1944 Nemocardium (Pratulum) semitectum; Marwick, T.R.S.N.Z. 74(3): 265.

1966 Nemocardium (Pratulum) semitectum; Fleming, N.Z. D.S.I.R. Bull. 173: 28, pl. 35, fig. 376.

DIAGNOSIS: A small, rotund Pratulum with about 80 fine, smooth costellae on central and anterior parts of shell, becoming narrow threads near anterodorsal margin, and about 35 somewhat coarser costellae bearing fine tubercles on posterior area, weaker and more widely spaced near posterodorsal margin.

DIMENSIONS OF HOLOTYPE (l.v.): Length 13.5, height 13.5, inflation (1 valve) 6 mm.

HOLOTYPE: TM 4502, N.Z. Geological Survey.

TYPE LOCALITY: GS 831, Lorne, North Otago (Kaiatan).

LOCALITIES: Lorne; GS 9884, Trig. M, Totara, North Otago (Runangan); GS 11,214, Bridge Point, Kakanui, North Otago (Runangan); GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

STRATIGRAPHIC RANGE: Kaiatan-Runangan.

REMARKS: The specimens from GS 9508 are mostly fragmentary, but the best preserved shell, a right valve measuring 9.8 x 8.5 mm agrees

rather closely with topotypes of semitectum in shape and sculptural features.

Superfamily TELLINACEA

Family TELLINIDAE

Subfamily TELLININAE

Genus Moerella Fischer

1887 Man. Conch.: 1147.

/Nom. subst. pro Moera H. & A. Adams, 1856, non Moera Huebner, 1819, nom. subst. pro Donacilla Gray, 1851, non Donacilla Blainville, 1819/.

Type species (by monotypy): Tellina donacina Linnaeus, 1758, Recent, Europe.

Moerella aotea n.sp. Pl. 1, figs. 11, 12.

DESCRIPTION: Shell small, hatchet-shaped, beak set at posterior two thirds. Anterodorsal margin long, very gently convex, descending moderately steeply to merge smoothly with the well-rounded anterior margin. Posterodorsal margin lightly convex, steeply descending, junction with ventral margin bluntly angled. Ventral margin broadly convex except for an ill-defined, shallow concavity near posterior end. A well-rounded ridge running from beak to posteroventral angle defines a narrow, rather flat posterior area. Concentric sculpture present on posterior area, on ventral half of middle portion of disc and near anterior margin, but absent from a broad area extending from beak towards anterior end. Sculpture consists of low, narrow, rounded or flattish ridges with narrow, usually linear interstices, weakening anteriorly to become fine grooves. No radial sculpture. Hinge rather light, right valve with an oblique, lamellar anterior cardinal

and a narrowly triangular, bifid posterior cardinal directly below beak. Anterior lateral tooth lamellar, rather long, separated from anterodorsal margin by an elongate deep socket. Posterior lateral tooth considerably shorter and closer to beak, an elongate socket above. Ligament groove not well preserved, apparently about one third length of posterodorsal margin. Left valve hinge not known. Other internal features not seen, because of corrosion.

DIMENSIONS OF HOLOTYPE (r.v.): Length 14.0, height 8.6, inflation 1.7 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9507, lower part of Ngapuke Member, immediately above "phosphatic" band, McCullough's Bridge (Bortonian) (holotype and 1 damaged paratype).

REMARKS: In the absence of the left valve, this species is only tentatively referred to Moerella, which is characterised by having the left anterior and posterior lateral teeth rather weakly developed. The small size and strongly inequilateral shape, however, indicates closer relationship to Moerella than to Tellinella Moerch, 1853, to which several New Zealand tellinids have been referred. No other species of Moerella have been described as such from New Zealand, but the Opoitian-Recent species Tellina huttoni E.A. Smith, 1885 may belong here (Dr C.A. Fleming, pers. comm.). This species differs from Moerella aotea in its thinner shell, lighter hinge and weaker sculpture.

Superfamily VENERACEA

Family VENERIDAE

Subfamily VENERINAE

Genus Marama Marwick

1927 Trans. N.Z. Inst. 57: 601-2.

Type species (original designation): Marama murdochi Marwick, 1927, Pliocene, New Zealand.

Marama (Marama) pristina Marwick, 1927

1927 Marama pristina Marwick; T.N.Z.I. 57: 603, pl. 43, figs. 105-6.

1966 Marama (Marama) pristina; Fleming, N.Z. D.S.I.R. Bull. 173: 28, pl. 39, figs. 420, 422 (not 421, 422 as in caption).

DIAGNOSIS: A small, elongate Marama with prominent beak and concentric sculpture of strong, somewhat irregular lamellae.

DIMENSIONS OF HOLOTYPE (r.v.): Length 22.4, height 16.5, inflation (1 valve) 6.6 mm.

HOLOTYPE: TM 4521, N.Z. Geological Survey.

TYPE LOCALITY: McCullough's Bridge. The holotype is set in iron-oxide stained greensand that could have come from a weathered outcrop of the Tahu Member (e.g. just below the terrace gravels) or from the lower part of the section (i.e. Kaiatan or Bortonian).

REMARKS: No additional specimens of this species are known, but the holotype at least is quite distinct from the younger species of Marama.

Subgenus Hina Marwick

1927 Trans. N.Z. Inst. 57: 602.

Type species (original designation): Marama (Hina) pinguis Marwick, 1927, Lower Miocene, New Zealand.

Marama (Hina) vaga Marwick, 1927

1927 Marama (Hina) vaga Marwick; T.N.Z.I. 57: 605.

1942 Marama (Hina) vaga; Marwick, T.R.S.N.Z. 72(3): 271, pl. 24, figs. 23, 24.

1966 Marama (Hina) vaga; Fleming, N.Z. D.S.I.R. Bull. 173: 29, pl. 40, figs. 433, 4.

DIAGNOSIS: A comparatively small, subrhomboidal Hina with concentric sculpture of narrow, low lamellae. Pallial sinus short, right-angled.

DIMENSIONS OF HOLOTYPE (r.v.): Length 22, height 19.5, inflation (1 valve) 7.1 mm.

HOLOTYPE: TM 4532, N.Z. Geological Survey.

TYPE LOCALITY: GS 630, "Teaneraki", i.e. Waihao R., possibly mouth of Pinnacle Gully (? Kaiatan).

LOCALITIES: McCullough's Bridge - GS 9508 (2 right valves), R.S. Allan Colln (1 right valve; also a left valve which probably belongs here).

REMARKS: The left valve (in the R.S. Allan collection) measures 31 x 26 x 9.5 mm and is considerably larger than any of the other specimens of vaga (all right valves). The anterodorsal margin descends more steeply, the sculpture undergoes an abrupt change at about 17 mm from the beak, from well-spaced thin lamellae to much finer and more closely-spaced ridges and the escutcheon is better

defined. In other respects it resembles the right valves.

Genus Kuia Marwick

1927 Trans N.Z. Inst. 57: 597.

Type species (original designation): Chione vellicata Hutton, 1873, Oligocene-Lower Miocene, New Zealand.

Kuia aff. vellicata (Hutton, 1873).

1873 Chione vellicata Hutton; Cat. Tert. Moll. N.Z.: 21.

1886 Venus meridionalis Sowerby; Hutton, T.N.Z.I. 18: 362 (not of Sowerby).

1914 Chione meridionalis (Sowerby); Suter, N.Z.G.S. Pal. Bull. 8: 51. Pl. 14, fig. 4.

1917 Chione (Ventricoloidea) vellicata; Cossman in Marshall, T.N.Z.I. 49: 462.

1917 Cytherea (Circomphalus) chariessa Suter; N.Z.G.S. Pal. Bull. 5: 74. Pl. 10, figs. 3, 4.

1924 Antigona vellicata (= C. chariessa); Finlay, T.N.Z.I. 55: 505.

1927 Kuia vellicata; Marwick, T.N.Z.I. 57: 600-1, Text figs. 1, 2. Pl. 42, figs. 92-5

1965 Kuia vellicata; Boreham, N.Z.G.S. Pal. Bull. 37: 61-2. Pl. 17, fig. 6.

1966 Kuia vellicata; Fleming, N.Z. D.S.I.R. Bull. 173: 29. Pl. 41, figs. 440-7.

1969 Dosina (Kuia) vellicata; Keen in Moore, Treatise Invert. Paleont.: N672.

A single small left valve of a venerid from McCullough's Bridge closely resembles the common mid-Cenozoic species Kuia vellicata,

differing in having the anterior cardinal tooth much more weakly bifid and in other minor hinge details. Such differences may prove to be consistent and of taxonomic value when more specimens are available.

DIMENSIONS (of McCullough's Bridge shell): Length 16.0, height 13.5, inflation 4.7 mm.

TYPES: Lectotype C. vellicata; TM 2884, N.Z. Geological Survey. Holotype C. chariessa; TM 4539, Suter Colln, N.Z. Geological Survey.

TYPE LOCALITY: C. vellicata; Awamoa (Altonian). C. chariessa; Trig Z, Otiake (Waitakian).

LOCALITIES: Numerous localities of Waitakian-Altonian age in North Otago and South Canterbury; GS 9480, McCullough's Bridge (Kaiatan).

REMARKS: Kuia has not previously been recorded before the Duntroonian; apart from the McCullough's Bridge species, however, it is now known from a Bortonian shellbed in the Pareora River. The Bortonian species is considerably more elongate than K. vellicata.

Order MYOIDA

Superfamily MYACEA

Family CORBULIDAE

Subfamily CORBULINAE

Genus Notocorbula Iredale

1930 Rec. Austral. Mus. 17: 404.

Type species (original designation): Notocorbula vicaria Iredale, 1930, Recent, N.S.W.

In the most recent classification of the Corbulidae (Keen in Moore 1969: N692-8), Notocorbula is treated as a subgenus of Corbula

Bruguiere 1797. However, Corbula s.str. lacks a projecting chondrophore in the left valve, whereas Notocorbula has a well-developed "bipartite" chondrophore, a feature which seems important enough to warrant separation of these taxa at the generic level.

Notocorbula allani n.sp. Pl. 9, figs. 100, 101.

DESCRIPTION: Shell small, trigonal, inequivalve, strongly inflated. Right valve considerably larger than left, ventral and posterior margins overlapping. Right valve with typical corbulid double structure, inner layer considerable smaller than outer, line of concresence clearly marked on shell interior. Umbones high and prominent, beaks at anterior three fifths. Nepioconch large, raised slightly above rest of shell. Anterodorsal margin descending steeply, almost straight or slightly concave; posterodorsal margin descending less steeply, longer than anterodorsal margin, somewhat concave, particularly where it forms the short, blunt rostrum. Ventral margin moderately convex, joining anterodorsal margin smoothly, posteroventral junction subangled. A weak, rounded ridge runs from umbo to lower rostral angle defining a posterior area. Escutcheon weakly defined, depressed. Sculpture consisting of prominent, rounded concentric costae with somewhat narrower interspaces. On nepioconch, costae maintain a fairly constant width across shell, but on adult are broadest just behind middle, narrowing quickly on either side. Similarly, the intercostal spaces are wider medially than elsewhere. Costae decrease in strength rather sharply on posterior area but do not become obsolete. Hinge rather narrow, a single peg-like cardinal tooth immediately beneath beak and shallow grooves in front and behind to take the dorsal margins of the left valve. Behind the cardinal tooth is a sunken triangular resilifer. Adductor muscle scars very large, anterior scar ovate,

posterior scar slightly larger, subcircular, pallial line with a broad, shallow arcuate sinus. Left valve subelliptical, dorsal margins short and gently convex, anterior margin rounded, posterior weakly truncated, almost straight. Ventral margin evenly convex, junction with posterior end weakly subangled, junction with anterior margin well-rounded. Nepioconch large, projecting, sculptured with narrow, rather irregularly spaced concentric costae, remainder of valve with weak growth ridges and having a rough, rather unfinished appearance. Hinge comparatively heavy, a deep triangular socket below beak to receive right cardinal tooth, with a triangular projecting chondrophore behind, divided into two parts by a low radial ridge, the posterior part the larger. Other internal features as in right valve.

DIMENSIONS OF HOLOTYPE (d.v.): Length 11.1, height 8.6, inflation (2 valves) 7.0 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

LOCALITIES: McCullough's Bridge - not uncommon in Tahu Member: GS 9508 (holotype and 25 paratypes); GS 9480 (10 paratypes); R.S. Allan Colln (9 paratypes); GS 9507, lower part of Ngapuke Member (Bortonian) (1 paratype); Pahi Greensands, Northland (Bortonian) (recorded by Fleming 1950: 238 as "Notocorbula aff. humerosa (Hutton)").

STRATIGRAPHIC RANGE: Bortonian-Kaiatan.

REMARKS: Apparently the "Corbula speighti Allan MS" of Allan's list (1926c: 291). Notocorbula allani is very similar to N. humerosa (Hutton, 1885), a species originally described from Altonian beds at White Rock R., South Canterbury, and credited with an exceptionally long stratigraphic range (Bortonian-Kapitean) by Fleming (1966: 33), but differs in being more strongly rostrate, in having more elongate

Taxon	Locality	Stage	Length L (mm)	Height H (mm)	L / H
N. allani n.sp.	GS 9508, McCullough's Bridge (holotype)	Kaiatan	11.1	8.6	1.29
"	" " " (paratype)	"	10.2	8.1	1.26
"	" " " "	"	11.1	8.3	1.34
"	" " " "	"	11.4	8.9	1.28
"	" " " "	"	11.0	8.1	1.36
"	" " " "	"	10.5	7.9	1.33
"	" " " "	"	10.5	8.4	1.25
"	" " " "	"	10.4	7.8	1.33
"	" " " "	"	11.2	8.7	1.29
"	GS 9507, " " "	Bortonian	8.9	7.0	1.27
"	Pahi, Kaipara Harbour, Northland (paratype)	"	9.0	6.6	1.36
N. humerosa (Hutton)	GS 165, White Rock R., S. Canterbury (topotype)	Altonian	14.1	12.1	1.17
"	" " " "	"	8.2	7.3	1.12
"	" " " "	"	9.0	7.8	1.15
"	GS 475, Mt Harris, S. Canterbury	"	8.2	6.7	1.22
"	" " "	"	7.9	6.6	1.20
"	" " "	"	7.1	6.1	1.16
"	Ardgowan Shellbed, Oamaru	"	8.8	7.8	1.13
"	" " "	"	7.3	6.6	1.11
"	" " "	"	7.2	6.6	1.09
"	" " "	"	7.9	6.8	1.16
"	GS 951, Target Gully Shellbed, Oamaru	"	8.7	8.1	1.07
"	" " " "	"	8.0	6.9	1.16

Table 9. Dimensions of right valves of Notocorbula allani n.sp. and N. humerosa (Hutton)

valves (see Table) and a larger resilifer in the right valve. The best-preserved of the shells from Pahi and the specimen from GS 9507 have length/height ratios which fall within the range recorded for the type sample and are considered to be conspecific.

Genus Caryocorbula Gardner

1926 Nautilus 40(2): 46.

Type species (original designation): Corbula alabamiensis Lea, 1833, Middle Eocene, Alabama.

Caryocorbula robini n.sp. Pl. 2, figs. 21, 22.

ETYMOLOGY: As with the previous species, this corbulid is named for the late Prof. Robin Sutcliffe Allan.

DESCRIPTION: Shell small, subquadrate, inequilateral, strongly inequivalve, right valve overlapping left ventrally and posteriorly. Right valve with prominent umbo, beak at anterior three fifths; anterodorsal margin steep, almost straight, merging smoothly with the well-rounded anterior margin; posterodorsal margin also nearly straight, short, descending less steeply than anterodorsal margin, junction with the gently convex posterior margin subangled. Ventral margin weakly sinuous, lowest point behind middle, at about posterior three fifths, margin convex behind, weakly concave in front. Junction with anterior margin well-rounded, with posterior margin subangled. A well-defined but not sharp ridge running from umbo to posteroventral angle defines a rather broad, flattish posterior area. Escutcheon long and narrow, bounded by a prominent ridge. Nepioconch not projecting above rest of shell but marked by change in sculpture. Near the beak it is smooth and polished, a few feeble concentric grooves appearing distally. Concentric sculpture on adult shell consisting

of prominent rounded costae tending to be slightly wider somewhat behind middle than elsewhere, fairly regularly spaced near middle of disc but becoming increasingly less regularly spaced ventrally where interspaces may be wider than the costae. Costae show a general increase in size ventrally but occasional narrow costae may appear by intercalation. Costae weaken sharply on crossing umbonal ridge onto posterior area. Hinge rather light with a tubercular cardinal tooth almost directly below beak and a resilifer immediately behind and above, tucked up under umbo, almost out of sight. Slightly below and parallel to the dorsal margins are shallow grooves to take the dorsal margins of the left valve. Anterior adductor muscle scar ovate, posterior scar circular, larger. Pallial line descending vertically from posterior adductor scar, turning slightly towards posterior end thus forming a feeble sinus and then running parallel to ventral margin before swinging up to anterior scar. Left valve of similar shape to right valve, like it bearing a prominent umbonal ridge defining a broad flat posterior area. As in the right valve, the nepioconch is flush with rest of shell and almost smooth apart from weak concentric grooves. Sculpture on adult consists of narrow, sharp concentric costae with broad, flattish or slightly concave interspaces that often bear a few weak concentric threads or grooves. Hinge with a small socket below beak to take the right cardinal and a triangular, almost horizontal chondrophore with its posterior edge largely fused to the thickened posterodorsal shell margin. A small tubercle present on the posterior corner of the chondrophore at its junction with the shell margin. Resilifer triangular, on the posterior half of the chondrophore. Other internal features as in right valve.

DIMENSIONS OF HOLOTYPE (d.v.): Length 6.5, height 5.3, inflation (2 valves) 3.3 mm. /The left valve of the largest paratype (from GS 9480)

measures 7.5 x 5.6 x 2.4 mm/.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

LOCALITIES: McCullough's Bridge - GS 9508 (holotype and seven paratypes); GS 9480 (four paratypes); R.S. Allan Colln (paratype).

REMARKS: This is probably the species listed by Allan (1926: 291) as "Corbula pumila Hutton", which is widely recorded in the Lower Miocene of North Otago and South Canterbury, but pumila differs in having a rather less trigonal shape with somewhat finer concentric sculpture on the right valve but coarser concentrics on left valve. Caryocorbula waihaoensis Finlay and Marwick, 1937 (? late Dannevirke Series, Waihao R.) has a sharper umbonal ridge and stronger, more regular concentric sculpture than C. robini.

Order PHOLADOMYOIDA

Superfamily PANDORACEA

Family THRACIIDAE

Genus Thracia Sowerby

1824 in Blainville, Dict. Sci. nat. 32: 347.

Type species (by subsequent designation, Blainville, 1827): Thracia corbuloides Blainville, 1824, Recent, Mediterranean.

"Thracia" n.sp.

DESCRIPTION: Shell small, fragile, subquadrate, beak at about anterior three fifths. Anterodorsal margin gently convex, merging smoothly with convex anterior margin; posterodorsal margin almost straight, junction with strongly convex posterior margin apparently

rounded. Ventral margin broadly convex, becoming straighter posteriorly, junctions with anterior and posterior margins well-rounded. Escutcheon long and narrow, rather deeply impressed, especially near umbo where it becomes cleft-like. Sculpture of weak concentric growth lines and tiny papillae which are apparently not arranged in any regular pattern, either radially or concentrically, but are more prominent anteriorly and posteriorly than in central portion of shell. Hinge very light, with a single small, tongue-shaped cardinal tooth directed anteriorly in the right valve. Between this tooth and the anterodorsal margin is a space that may have acted as a socket for a left cardinal tooth. Ligament external, short, extending only one fifth the length of the posterodorsal margin. Muscle and pallial features not seen.

DIMENSIONS (r.v.): Length 11, height 8.5, inflation (right valve) 3.3 mm.

LOCALITY: GS 9480, McCullough's Bridge (Kaiatan) (1 right valve).

REMARKS: This species is referred to Thracia in a broad sense only, as there is no trace of a chondrophore or lithodesma in the sole specimen. The external ligament suggests Thracia, but the presence of a cardinal tooth and the absence of granular shell-texture are quite anomalous features. Thracidora Iredale, 1924 may be a more apt location, as the type species (Thraciopsis arenosa Hedley, 1904) has an external ligament and sculpture of tiny sharp "grains". However, arenosa lacks a cardinal tooth and has the sculpture arranged in radial rows rather than randomly. Until further material becomes available, then, the taxonomic position of the McCullough's Bridge shell must remain uncertain.

Superfamily POROMYACEA

Family CUSPIDARIIDAE

Genus Cuspidaria Nardo

1840 Atti Riun. Sci. Ital. 1, 1839: 175.

Type species (by monotypy): Cuspidaria typus Nardo, 1814 (= Tellina cuspidata Olivi, 1792), Recent, north-east Atlantic-Mediterranean.

Cuspidaria cf. fairchildi Suter, 1908

1908 Cuspidaria fairchildi Suter; T.N.Z.I. 40: 372. Pl. 29, fig. 19.

1913 Cuspidaria fairchildi; Suter, Man. N.Z. Moll.: 1036. Pl. 54, fig. 16, 16a.

1956 Cuspidaria fairchildi; Dell, Dom. Mus. Bull. 18: 38. Pl. 6, fig. 51.

1963 Cuspidaria fairchildi; Dell, T.R.S.N.Z. (Zool.) 3(30): 207.

1966 Cuspidaria fairchildi; Fleming, N.Z. D.S.I.R. Bull. 173: 35.

1971 Cuspidaria fairchildi; Powell, Rec. Auck. Mus. 8: 228. Figs. 29-31.

DESCRIPTION (McCullough's Bridge specimen): Shell small, fragile, club-shaped, the posterior end produced to form a long rostrum. Umbo prominent, at about anterior seven tenths. Anterodorsal margin almost straight, merging smoothly with well-rounded anterior margin; posterodorsal margin slightly concave, descending slowly at first, then becoming almost horizontal on reaching the rostrum. Ventral margin joining anterior margin smoothly, gently concave at inception of rostrum, almost straight posteriorly, otherwise broadly convex. Posterior margin short, gently convex, forming the end of the long, slowly tapering rostrum. Shell strongly inflated medially, constricted

behind, a rounded ridge running from umbo to lower corner of rostrum and bounded below and in front by a broad, shallowly concave area. Sculpture subdued, consisting of low concentric growth ridges which are strongest on posterior portion of disc and on rostrum, but largely obsolete on remainder of shell. Hinge very light, rather weakly buttressed, with a narrow, almost vertical resilifer beneath beak in left valve, posterior lateral tooth weakly defined, little more than a slight thickening of shell adjacent to the posterodorsal margin, well separated from resilifer. Other internal features not seen.

DIMENSIONS (l.v.): Length 9.2, height 4.3, inflation 1.7 mm.

HOLOTYPE: National Museum, Wellington.

TYPE LOCALITY: Off Flat Pt, North Island, 75 faths (137 m).

LOCALITIES: Recent; recorded from around New Zealand, mostly at bathyal depths but also on the continental shelf (Dell 1956b: 38-9). Fossil; recorded from Opoitian to Recent by Fleming (1966: 35). GS 9508, Tahu Member, McCullough's Bridge (Kaiatan) (1 small left valve).

STRATIGRAPHIC RANGE: Kaiatan-Recent.

REMARKS: The small McCullough's Bridge shell cannot be satisfactorily distinguished from Recent specimens of C. fairchildi of similar size and is therefore considered to be conspecific. The implied stratigraphic range is unusually long for a New Zealand bivalve but is emulated by Hiatella arctica (Linnaeus) which is also first known from the Kaiatan (GS 9481, Lorne) and ranges up to the present day.

Finlay and Marwick (1937: 104) noted that a badly decorticated Cuspidaria from Castle Hill Shaft, Kaitangata (? Upper Dannevirke Series) has the shape of C. fairchildi, which suggests that the stratigraphic range of this species is even greater than that given

above.

Family VERTICORDIIDAE

Genus Verticordia J. de C. Sowerby

1844 Mineral Conchology 7(112): 67.

Type species (by monotypy): Hippagus? cardiiformis Sowerby, 1844, Pliocene, England.

Subgenus Spinosipella Iredale

1930 Rec. Austral. Mus. 17: 388.

Type species (original designation): Verticordia ericia Hedley, 1911, Recent, south-east Australia, New Zealand, southern Africa.

Verticordia (Spinosipella) n.sp.

A broken left valve of a verticordiid from McCullough's Bridge resembles V. ericia in its small size (originally about 5.2 x 4.5 mm) and radial sculpture of high, narrow widely spaced costae bearing tiny spines on both crests and flanks. Between the costae are radial rows of small papillae. No other fossil records of the subgenus from New Zealand are known to the writer, but an undescribed species is present in the Glen Aire Clay (Upper Eocene) of Victoria, Australia (coll. A.G. Beu).

LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

Class SCAPHOPODA

Family DENTALIIDAE

Genus Dentalium Linnaeus

1758 Syst. Nat. ed. 10: 785.

Type species (by subsequent designation, Montfort 1810): Dentalium elephantinum Linnaeus, 1758, Recent, western Pacific.

Subgenus Fissidentalium Fischer

1885 Man. de Conchyl.: 894.

Type species (by monotypy): Dentalium ergasticum Fischer, 1882, Recent, Atlantic Ocean.

Dentalium (Fissidentalium) waihaoense n.sp. Pl. 10, figs. 114, 115, 118, 119.

DESCRIPTION: Shell moderately large and robust, rather slowly tapering, gently curved near apex, tending to become straighter anteriorly. More complete shells showing a long, narrow apical slit on convex side. Aperture thin, elliptical, compressed dorso-ventrally, degree of compression apparently less pronounced in large shells than in subadult ones. Longitudinal sculpture commencing as about 15-16 narrow, raised, rounded costae with broad, almost flat interspaces. Additional costae appear by intercalation at varying stages of growth, sometimes rivalling the primary costae in strength anteriorly but often remaining considerably weaker, so that in some parts of the shell there may be an alternation of strong and weak costae. "Tertiary" costae may also appear between primary and secondary costae. Total number of costae at apertural end variable, as many as 45 in largest shells. Near aperture all costae become subdued though not completely obsolete. Well-preserved shells also

show numerous very fine longitudinal threads between the costae. Transverse sculpture of numerous fine, raised growth-lines moderately prominent in intercostal spaces but almost completely obsolete on the costae themselves. A finely reticulate effect is produced by the intersection of the growth lines with the intercostal threads.

DIMENSIONS (mm):	Length	Apertural diameters
Holotype	50.4	8.3 x 6.6
Paratype (GS 9508)	64.2 (incomplete)	9.9 x 9.2

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan).

LOCALITIES: Common in all collections from Tahu Member at McCullough's Bridge; GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (1 fragment that probably belongs here).

REMARKS: Dentalium waihaoense is remarkably similar to the Manga-panian-Recent species D. zelandicum Sowerby, 1860, apparently differing only in having a longer apical slit and narrower primary costae. The two species may be closely related, but as no zelandicum-like shells are known from post-Kaiatan, pre-Wanganui Series faunas, it is possible that their similarity is quite fortuitous (i.e. that they are "heterochronous homeomorphs").

Dentalium centenniale Marwick, 1942 (Bortonian, Hampden), the only other New Zealand Eocene ribbed Dentalium so far described, has more numerous primary costae (about 26 in holotype) and weaker intercostal threads than D. waihaoense and more prominent growth lines that cross the costae virtually unchanged. D. centenniale apparently grows to a much larger size than D. waihaoense; a broken topotype (from GS 11,155, Hampden) measures about 61 x 13.5 mm.

The large, rather solid shell with long, narrow apical slit and longitudinal sculpture of numerous narrow costae indicates assignment of this species to Fissidentalium. Habe (1963: 260) has proposed the taxon Compressidentalium (type species D. hungerfordi Pilsbry & Sharp, Recent, China and Japan) as a subgenus of Fissidentalium for species with dorso-ventrally compressed shells and this may well be a more apt location for D. waihaoense.

Dentalium (? Fissidentalium) delli n.sp. Pl. 10, figs. 109, 110.

DESCRIPTION: Shell of moderate size for genus, slowly tapering, only gently curved, slightly compressed dorso-ventrally, apical slit very long and narrow, seen only on one fragmentary shell, possibly an artifact. Aperture apparently thin and circular, but no complete examples seen. Longitudinal sculpture consisting primarily of about 14-18 narrow, rounded costae with smooth, flattish interspaces, secondary and some tertiary costae appearing at varying stages during growth, all tending to become subequal anteriorly. Transverse growth lines weak, often almost totally absent. Shell exterior with a distinctive thin glaze.

DIMENSIONS (mm):	Length	Apertural diameters
Holotype	44.5 (incomplete)	6.4 x 5.8
Paratype (GS 9508)	37.2 (")	5.7 x 5.4

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 1162, McCullough's Bridge (probably Kaiatan).

LOCALITIES: Common in all collections from Tahu Member, McCullough's Bridge; GS 3274, Highcliff Siltstone Member, McCullough's Bridge (Kaiatan) (several fragments); GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (several fragmentary shells); GS 4872, Point Elizabeth

Beach, Greymouth (Kaiatań) (several fragmentary shells that agree well with Waihao shells).

REMARKS: Dentalium delli differs from the sympatric D. waihaoense in its smaller size, more graceful form, finer longitudinal costae (although the number of primary costae is similar in both species), weaker growth lines, absence of intercostal longitudinal threads and presence of a glaze over the shell surface. Dentalium mantelli Zittel, 1864, may be related to either waihaoense or delli, but it is still a very poorly known species, even after more than a century of paleontological research. Zittel (1864: 45) recorded D. mantelli from The Cliffs, Nelson, and Awatere R. (both localities collected by F. von Hochstetter) and from Onekakara (Hampden), collected by Walter Mantell, without, however, designating a type locality. Zittel's choice of the name mantelli may suggest that he had a Hampden shell in mind as the type, but both of the specimens of D. mantelli figured by him (pl. 13, figs. 7a, b) are from The Cliffs, Nelson. Suter (1914: 32) stated that the type of D. mantelli was in the K.K. Hofmuseum, Vienna, which Marwick (1942: 279) took to imply that Zittel based his species on Hochstetter's material, although it is quite possible that Mantell donated his specimens to Zittel for study. Marwick thought that Suter's action "is best taken as a designation of type", but in fact, it is nothing of the sort as, even if Mantell's Hampden material is excluded, we are left with two possible type localities, viz. The Cliffs, Nelson and Awatere Valley. Since Zittel's figured specimens are from The Cliffs (which is a far more restricted locality than "Awatere Valley") and as this has been accepted as the type locality by subsequent workers, the safest course is to select one of the shells figured by Zittel as the lectotype. Accordingly the shell illustrated as fig. 7b is so selected, but it

should be pointed out that Flugel (1959) apparently was unable to trace any type material for D. mantelli in the K.K. Hofmuseum, Vienna. [Cotton & Ludbrook (1938: 223) concluded that "one must accept Zittel's figured specimen from The Cliffs as the holotype", but Zittel actually figured 2 shells, so a lectotype must be designated]. Judging from Zittel's figures, Dentalium mantelli is more strongly curved than D. delli and has fewer and stronger costae. A few poorly preserved fragments of Dentalium from GS 1207, The Cliffs, possibly but not certainly assignable to D. mantelli, differ from the Waihao species in their more robust and larger shells in which the costae become very low and flat with linear interstices towards the anterior end. There seems little doubt that Dentalium mantelli (from a locality of about Duntroonian age) is quite distinct from either D. waihaoense or D. delli, but it remains a most unsatisfactory species.

Genus Fustiaria Stoliczka

1868 Mem. Geol. Surv. India. Paleontologica Indica 5(2): 439.
Type species (by subsequent designation, Pilsbry & Sharp 1897): Dentalium circinatum Sowerby, 1823, Eocene, Paris Basin.

Fustiaria (Fustiaria) beui n.sp. Pl. 10, figs. 111-3.

DESCRIPTION: Shell of moderate size, thin near aperture but otherwise rather robust, gently curved near apex, gradually tapering, tending to be weakly constricted at irregular intervals. Apical details unknown. Aperture probably originally circular. Transverse sculpture of irregularly spaced, very fine grooves; no longitudinal sculpture.

DIMENSIONS OF HOLOTYPE: Length (apex missing) 56.6 mm, apertural diameters (distorted by crushing) 6.0 x 7.5 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9508, Tahu Member, McCullough's Bridge (Kaiatan) (holotype and 2 fragmentary paratypes).

REMARKS: This is the only species of Fustiaria s.str. so far recorded from New Zealand. Three species of Laevidentalium Cossmann, 1888 [treated as a subgenus of Fustiaria by Emerson (1962: 472-3)] have been described from the Cenozoic, but the types of two of these, viz. Dentalium pareorense Pilsbry & Sharp, 1897 (= D. laevis Hutton, 1873, not of Schlotheim, 1820) (?Kapitean-Waipipian, Kaniere) and Laevidentalium multistrictum Finlay & Marwick 1937 (Wangaloan, Wangaloa) have weak longitudinal sculpture and should probably be referred to Antalis H. & A. Adams 1854 or to Graptacme Pilsbry & Sharp 1897). The remaining species, Dentalium waihoraense Emerson 1954 [= D. (Laevidentalium) filum Marwick 1931, not of Sowerby 1860] (Altonian-Clifdenian, Waihora R.) is a small, slender species lacking both longitudinal and transverse sculpture and is probably best retained in Laevidentalium.

The 3 specimens comprising the type material of Fustiaria beui were collected by Dr A.G. Beu (to whom the species is dedicated) and the writer during a visit to McCullough's Bridge in October 1972; no additional specimens have been located in earlier collections.

Subgenus Gadilina Foresti

1895 Bull. Soc. Malacol. Italiana 19: 259.

Type species (by monotypy): Dentalium triquetrum Brocchi, 1814, Miocene, Italy.

Fustiaria (Gadilina) maoria n.sp. Pl. 10, figs. 116, 117.

DESCRIPTION: Shell of moderate size, moderately curved near apex, of subtrigonal cross-section, especially in young specimens, dorsal surface slightly flattened, producing a weak, rounded, longitudinal keel along each side, sides convex. Apical features poorly known, but a short terminal pipe observed in a juvenile shell from GS 11,200; aperture thin, oblique, apparently almost circular. Shell surface highly polished, no sculpture apart from very fine growth lines.

DIMENSIONS OF HOLOTYPE: Length (almost complete) 41.5 mm, approximate apertural diameter, allowing for lateral crushing, 4.5 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 1986, McCullough's Bridge (probably from Tahu Member, i.e. Kaiatan).

LOCALITIES: McCullough's Bridge - fairly common in collections from Tahu Member but usually represented by small fragments; GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (common).

REMARKS: The subtrigonal cross-section, weak longitudinal keels and absence of sculpture indicate that this species belongs in Gadilina, the first to be described from New Zealand. A distinct species with considerably sharper longitudinal keels and more definite trigonal cross-section and fine transverse grooves is present in GS 3301, Kaiata Siltstone (Kaiatan), Inangahua-Westport Rd.

Emerson (1962: 472) gives the distribution of Gadilina as "Miocene-Recent, Europe, East Indies", apparently overlooking the South Australian Upper Eocene species Dentalium tatei Pilsbry & Sharp, 1898 (= D. triquetrum Tate, 1887, not of Brocchi 1814), referred to Gadilina by Tate (1899: 266). Gadilina tatei is smaller, straighter, with sharper keels than G. maoria and may be related to the undescribed Kaiatan species mentioned above (see figures of G. tatei in Ludbrook 1959: pl. 1, fig. 5).

Family SIPHONODENTALIIDAE

Genus Cadulus Philippi

1844 Mollusc. Siciliae 2: 209.

Type species (by monotypy): Dentalium ovulum Philippi, 1844, Recent, Mediterranean.

Subgenus Gadila Gray

1847 Proc. zool. Soc. London 15: 159.

Type species (original designation): Dentalium gadus Montagu 1803, Recent, Europe.

Cadulus (Gadila) cf. zecaninus Laws 1939

1939 Cadulus zecaninus Laws, T.R.S.N.Z. 68: 503, Pl. 63, fig. 18.

1966 Cadulus zecaninus; Fleming, N.Z. D.S.I.R. Bull. 173: 35.

DIAGNOSIS: A minute, tubular, rather inflated Cadulus with maximum diameter near middle, gently concave dorsally and moderately strongly convex ventrally. Apical orifice simple.

DIMENSIONS OF HOLOTYPE: Length 3.5, diameter at aperture 0.5,

greatest diameter 0.85 mm.

HOLOTYPE: TM 1374, N.Z. Geological Survey

TYPE LOCALITY: Pakaurangi Point, Kaipara Harbour (Late Otaian or early Altonian).

LOCALITIES: Pakaurangi Pt; McCullough's Bridge: GS 9480 (probably Kaiatan) (1 shell); GS 9508, Tahu Member (Kaiatan) (2 shells).

STRATIGRAPHIC RANGE: ?Kaiatan-Otaian or Altonian.

REMARKS: The Waihao shells tend to be more inflated medially than the holotype, but insufficient material is available from either McCullough's Bridge or Pakaurangi Point to be confident that this distinction is consistent.

Subgenus Polyschides Pilsbry & Sharp

in 1898 Tryon & Pilsbry, Man. Conch. 17: 142, 146.
Type species (original designation): Cadulus tetraschistus Watson 1879, Recent, Brazil.

Cadulus (Polyschides) arnoensis n.sp. Pl. 3, figs. 23, 24.

ETYMOLOGY: Named after Arno, formerly a station on the Waimate-Waihao Downs line, about 3 km north of McCullough's Bridge.

DESCRIPTION: Shell small, slender, dorsal side gently concave posteriorly, almost straight in front, ventral side moderately convex. Greatest diameter of shell at about anterior three-quarters, tapering only slightly towards aperture. Apical orifice small, circular, with 2 narrow, moderately deep, lateral slits, 2 somewhat shallower dorsal slits and 2 considerably shallower triangular ventral notches (one of which is not well shown on the available specimens due to

damage to the lip). Aperture moderately large, oblique, subcircular.

DIMENSIONS (mm)	Length	Diameter at aperture	Greatest diameter
Holotype	8.6	1.0	1.45
Paratype (GS 9508)	10.5	1.1	1.75

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (probably from Tahu Member, i.e. Kaiatan).

LOCALITIES: McCullough's Bridge - GS 9480 (holotype); GS 9508, Tahu Member (2 paratypes).

REMARKS: Cadulus atavus Finlay & Marwick 1937 (?upper Dannevirke Series, Kaitangata) is rather similar to this and the following species and may be closely related, although the apical features are unknown. C. atavus is, however, far more swollen near the middle of the shell than either of the Waihao species. Cadulus delicatulus Suter 1913 (Recent, New Zealand) also has 6 apical slits (Dell 1957: 561-2), but these are more prominent and differently arranged from those in either C. arnoensis or C. kapuaensis.

Cadulus (Polyschides) kapuaensis n.sp. Pl. 3, figs. 29, 30.

ETYMOLOGY: Named after Kapua, a locality about 2 km north of McCullough's Bridge, famous as the site of a highly productive moa-bearing swamp.

DESCRIPTION: Shell similar to C. (Polyschides) arnoensis n.sp. but far more swollen at widest point (at about the same position as in C. arnoensis) so that dorsal side is slightly convex anteriorly. Apical features similar but with dorsal slits about the same length as the lateral slits instead of considerably shorter. Aperture

damaged, but apparently larger than in C. arnoensis.

DIMENSIONS OF HOLOTYPE: Length (not quite complete) 8.9, diameter at aperture 1.6 (est.), greatest diameter 1.95 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 11,200, Kapua Tuffs, Waihao R. (Kaiatan) (holotype and paratype).

Genus Entalina Monterosato

1872 Not. Conch. Pellegrino: 27.

Type species (by subsequent designation, Sacco 1897): Dentalium tetragonum Brocchi, 1814, Miocene, Italy and Austria.

Entalina emersoni n.sp. Pl. 3, figs. 27, 28.

DESCRIPTION: Shell very small, moderately curved, slowly tapering; subquadrate in cross-section, dorsal face wider and somewhat less convex than ventral face, lateral faces flat or lightly convex. Apical orifice almost circular, simple; aperture damaged in all specimens, apparently thin, oblique. Longitudinal sculpture consisting primarily of 5 narrow, rather sharp costae, 4 of them marking the edges of the faces, the other running along the middle of the ventral face. During growth, secondary and tertiary costae appear on all faces, those on dorsal and ventral faces tending to be stronger than those on lateral faces. Transverse sculpture of very fine growth lines only.

DIMENSIONS OF HOLOTYPE: Length (incomplete) 6.8, diameter at aperture (dorso-ventral) 1.1 mm.

HOLOTYPE: N.Z. Geological Survey.

TYPE LOCALITY: GS 9480, McCullough's Bridge (probably from Tahu Member, i.e. Kaiatan).

LOCALITIES: McCullough's Bridge - GS 9480 (holotype and paratype); GS 9508, Tahu Member (2 paratypes).

REMARKS: This is the first species of Entalina to be recorded from New Zealand. The longitudinal sculpture and simple, unconstricted aperture suggest reference to the Dentaliidae, but the anatomical features of living species indicate that Entalina is a siphonodentaliid (Emerson 1962: 475).